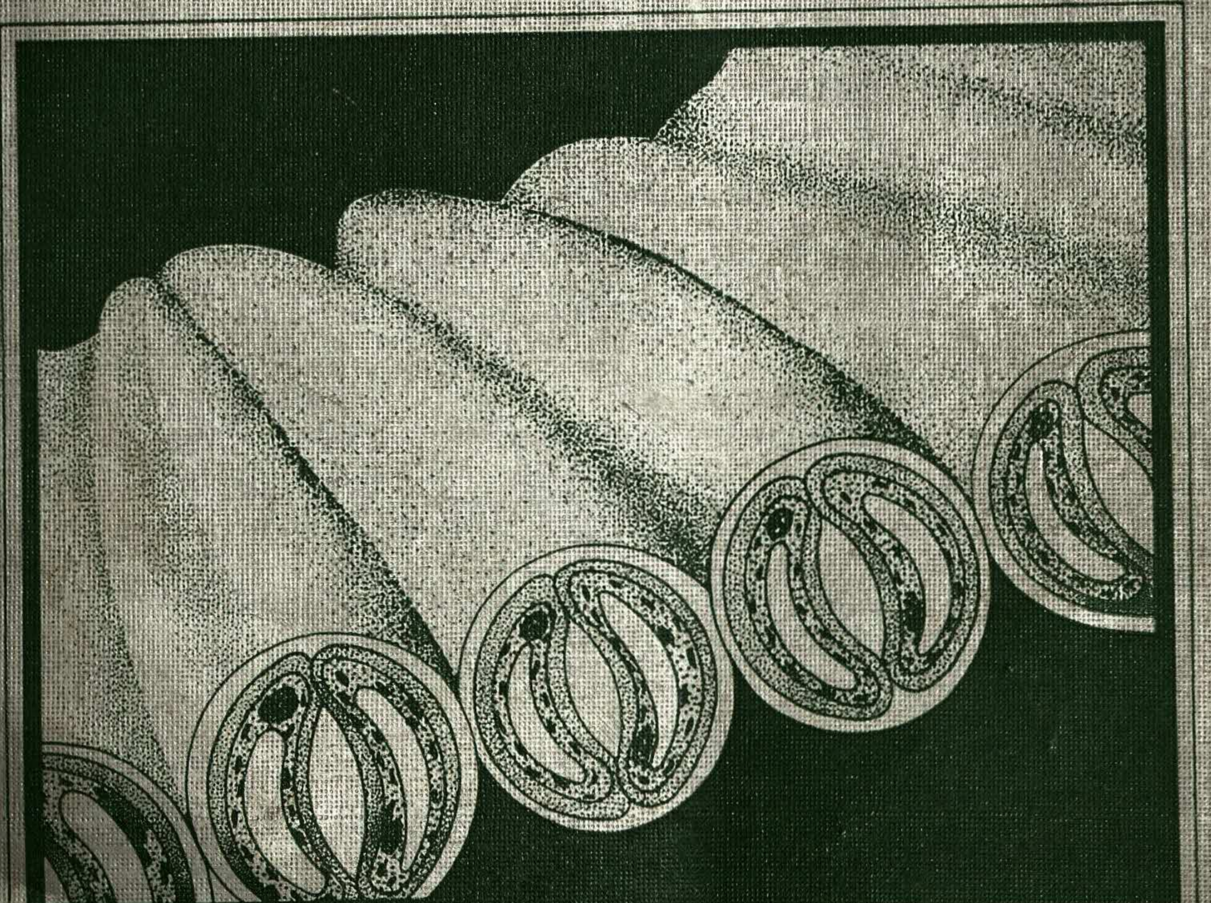
Modern Secondary Biology



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Modern Secondary
BIOLOGY

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To the Teacher

The introduction of the new system of school education has necessitated a reorientation of outlook on curricula as well as modes of instruction. This new textbook of Biology is an attempt to fulfil these needs of both the teacher and the student.

While completely covering the new syllabus for Classes IX and X we have constantly kept in mind the need to stimulate the imagination as well as the intellect of the student. The text has been written in the style of classroom teaching, with a careful gradation of vocabulary and syntax as the book progresses. The illustrations have been carefully selected to support and supplement the text and besides accurate line drawings a rich range of photographs has been included. The layout has been devised to achieve as aesthetic a form as possible, in the belief that the physical appearance of a book is as important as its content.

The book has been written in six parts, each of which deals with one major portion of the curriculum. Each of the twenty-nine chapters distributed over these parts is a unified treatment of a particular topic. Efforts have been made to retain unity even in the longer chapters in spite of their division into sections and sub-sections.

One important fact that deserves attention here: the sequence of parts and chapters on the subsequent pages does not follow that suggested in the syllabus. This deviation on our part was determined by choice of methodology. Contemporary approaches in Physics and Chemistry first introduce the student to atomic structure and elementary particles, and then obtain the properties of matter in bulk in terms of those electrons, protons, and neutrons in ensemble. A parallel synthetic approach in Biology appears to be desirable, because it is more instructive to the student than an analytical approach. Therefore, in its first two parts, the book establishes the basic facts about living organisms and the properties of the simplest forms of plant and animal life. In the next three parts it develops the concepts and methods, introduced earlier, to attain a fundamental understanding of the diversity and complexity of higher plants and animals. In the last part, the book focuses attention on the problems of human health and environment, an important consideration in our times. This synthetic method has enabled us to demonstrate the interdependence of organisms in nature, and the interrelationship of physical, chemical and biological processes. Thus, in discussing physiological division of labour, food chains, the energy cycle in nature, and the endocrine system in the human body, we have exemplified the logic of living systems. It is in perceiving this logic that the student will be able to pursue the quest of the biological sciences of our times.

Exercises have been included at the end of each chapter. These have been formulated with two ends in view: first, to test and to prepare him for the task of taking an examination; second, to instil in the student a willingness to observe and a capacity to think.

An additional and very important feature of the book is the inclusion of practical activities. These are simple experiments which require a minimal of sophisticated apparatus, and which every student should be encouraged to carry out independently. The activities will clearly demonstrate the various concepts and principles discussed in the text. This feature incorporates into the book the essential empirical basis of Biology.

We are indebted to numerous teachers for their help in preparing this work. In particular, we are very grateful to Dr Manohar Lal, Reader in Botany, University of Delhi, for amending the text and for his generosity in providing some of the photographs reproduced here; and to Longman Group for their permission to reproduce some of the illustrations from their book, New Biology for Tropical Schools. Doubtless, some errors still remain and we welcome correspondence from all teachers who use this book. Their constructive criticism should improve the book and bring it closer to its objectives.

K.K. KATYAL & MASRUR ALI

October 1989

To the Student

This textbook has been written, designed, and produced for your use. In order to help you to understand the science of Biology, it follows a straightforward pattern. It begins with the simplest facts and observations about living organisms. From these, it gradually develops the important ideas which will enable you to understand the more complex forms of life. All along, new concepts are introduced on the basis of what has been explained earlier. This will enable you to see clearly how living organisms are related to each other, how all forms of life on our planet are interdependent, and how Nature functions as a whole.

For your convenience this book has been divided into six parts and twenty-nine chapters. Each chapter deals with one major topic in your curriculum. Most of the chapters are divided into sections. You are expected to first carefully study each section of a chapter by itself. Then you should observe how the several sections form the chapter. At the end of each part of the book you should review the chapters in it and note how they have progressed. This procedure will ensure for you a thorough understanding and appreciation of Biology.

A great deal of effort has been made to present the subject precisely and interestingly. What the text describes in words, the many photographs and numerous drawings display visually. But you must not stop at these. A biologist's real place is in the laboratory and the natural world itself where he actually encounters the living organisms he wishes to understand.

Throughout the book important and new terms and words have been set in bold type. You must pay extra attention to these. Italics have been used only for the Latin names of various classes or organisms.

Practical activities have been outlined throughout the book. You must actually perform these experiments. All of them can be performed with simple apparatus at home, in the classroom, or in the laboratory. Exercises have been included at the end of each chapter. You must use these to test, clarify, and improve your understanding.

Among the natural sciences, it is Biology that has developed most extensively and rapidly in recent decades. If the first half of the twentieth century was the Age of the Atom, then the second half is the Age of the Cell. Almost every week exciting discoveries in it are being made the world over. It is probably the most important science for our times, and every individual who contributes to it will help to improve and sustain human and other life on our planet.

October 1989 K.K. KATYAL & MASRUR ALI

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Part 1: The Basic Structure, Organisation, and Functions of Living Organisms

CHAPTER 1

Living Organisms and Non-living Objects

In daily life, we encounter a very large number of objects. Almost every day we come across people, buildings, and vehicles; we utilise clothes, pens, and books; and we observe insects, birds, and animals. We must understand the nature of these objects in order not only to live with them but also to employ them for our benefit and welfare. For instance, we know that it would be dangerous to step in the way of a speeding car or drink unclean or impure water or tamper with a weapon. This knowledge enables us to minimise (if not avoid totally) accidents, disease, and destruction. Further, if we extend our knowledge to study about viruses and bacteria, we can try and prevent or cure many ailments; or else, if we master electronics, we can produce the precision instruments or sophisticated gadgets required for scientific research and for progress. The obvious question that arises is: How do we obtain useful knowledge about the objects around us? This can be done by using our own faculties of observation and intelligence, and by learning from knowledgeable people, books, practical experiments and other media such as radio, films, and television. We first need to grasp the facts and then arrange the information in a systematic and useful manner.

One manner of usefully arranging the facts about our world is the method of **classification.** Suppose we notice some similarities between two animals, say, a dog and a cat, i.e., both move on four limbs, both have a tail, two eyes, whiskers, and so on. If we study the two objects separately, we learn something about each. If we study their similarities, we learn something more about each. This leads us to consider classes or groups of objects which have some properties in common. Thus, we classify all individual objects and study their properties in terms of the classes to which they belong.

The first step in a useful classification of all the objects in the world is that of distinguishing **living organisms** from **non-living objects.** By taking this step, we clearly define the science called **biology** (which is the study of all living organisms), as different from the sciences called physics and chemistry (which are two ways of studying non-living things). To perform this classification, we have to answer the question: What are living organisms? Or, alternatively: What is life? It is not only extremely important but also very difficult to answer either question.

We know that human beings, sparrows, trees, snakes, earthworms, and mosquitoes are **alive**, whereas stones, bottles, scooters, and sheets of paper are not. However, when we study microscopic objects such as **viruses,** we do not know whether they are living or not. What, then, is life? It seems to be a mysterious quality possessed by some objects and not by others. No one has been able to satisfactorily define life. Nevertheless, most biologists agree that living objects can perform certain special functions or activities on their own which non-living objects cannot. This fact enables us to distinguish between the two. A living object can perform different life functions on its own and is therefore known as a **living organism.**

One of the peculiarities of living organisms is that after a specific period of time they permanently stop performing the functions of life. They are then said to be **dead.** Many non-living objects such as wood and leather are products of dead organisms. Other non-living materials, such as crystal and water, have never been alive. They are said to be **inanimate.** Thus, non-living can mean either dead or inanimate.

There are thus three types of objects around us—living, non-living, and dead. All varieties of animals and plants are living organisms. On the other hand, stones, bricks, bicycles, and steel cupboards are non-living objects. Your desk is made of wood; this wood was once a part of some living tree. The leather that is utilised in making shoes is obtained from the skin of some animal. Bread is formed from ground wheat grains. Wheat grains too were living some time back. Wood, leather, bread are all products of dead organisms and are, therefore, examples of dead objects. In this book, we shall be chiefly concerned with living organisms, and shall study their various characteristics and features in detail.

THE CHARACTERISTICS OF LIVING ORGANISMS

Living organisms have certain special properties or features or characteristics which the non-living objects do not: for instance, living organisms are born to or are formed from their parents. They grow, live for a fixed period, during which they produce more living organisms like themselves, and then die. Non-living objects do not have such characteristics.

Let us now study some of the characteristics of living organisms with the help of which we can easily and quickly distinguish them from non-living objects.

CELLULAR STRUCTURE

Just as buildings are made of bricks, all living organisms are made of units called **cells.** Simple organisms such as *Amoeba*, *Trypanosoma*, bacteria, *Chlamydomonas*, and *Euglena* have just one cell in their body and this single cell carries out all functions of life. On the other hand, human beings, lions, fishes, apple trees, rice plants, etc., have millions of cells in their body. These cells are organised into groups (called **tissues**) and organs to carry out the different functions of life.

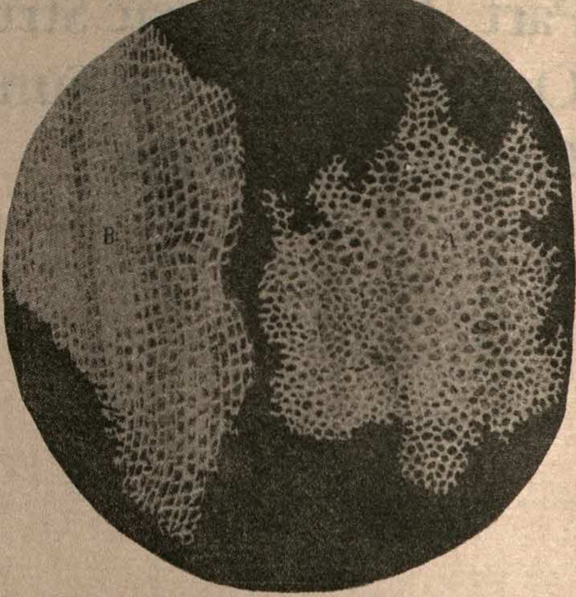


FIG. 1.1 **Drawings of cork cells made by Robert Hooke in 1665**

If we examine a thin peeling from the scale leaf of onion, we see compartments separated from each other by partitions. (Figure 1.1 shows a diagram relating to cork cells.) Each such microscopic compartment, enclosed by a wall, is called a cell. A cell consists of a living substance called **protoplasm** which has two main components, namely, a **nucleus** and surrounding **cytoplasm.** Protoplasm is a complex mixture of many chemical compounds of carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, calcium, and other elements. These compounds react with each other constantly and help in performing the functions of life in a cell. The sum total of these chemical reactions occurring within a cell and the living organism is known as **metabolism.**

MOVEMENT

We can move several parts of our body as we wish. We use our legs for walking or running; we bend our fingers to grip a bag; we shut our eyelids while sleeping. Similarly, other examples of movement are as follows. Plants push their roots deeper into the soil to obtain water and dissolved mineral salts from it. A climber turns round a support. Large

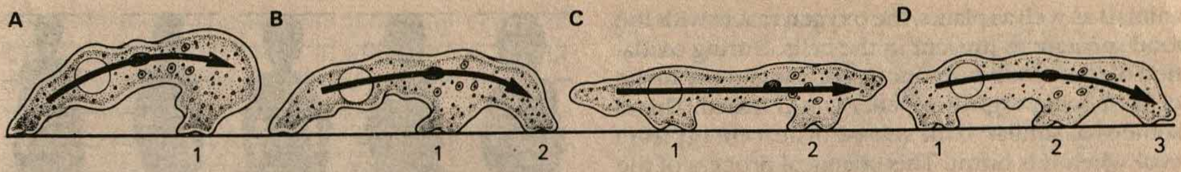


FIG. 1.2 Amoeboid movement

heads of the sunflower plant keep on turning towards the sun throughout the day. The growth of stems of all plants towards sunlight and closing of the leaflets of a sensitive plant, when it is touched, are also examples of movement. A majority of animals move from place to place (**locomotion**) in search of food and shelter. Even plants which remain fixed in the soil and some animals of this type, such as sea anemone, show some kind of movement going on in their bodies. Your pet dog may be lying fast asleep and motionless, but different kinds of movement are taking place within its body; e.g. beating of its heart, movement of its ribs, which helps in breathing, and movement of blood within its body. Even a small animal such as *Amoeba* moves with the aid of its **pseudopodia** (blunt finger-like projections from its body surface) [Fig. 1.2]. All such movements are peculiar to living organisms. Non-living objects do not move on their own. A boulder shifts only when it is pushed; water flows only under pressure; particles of sand are carried by the wind; and machines have to be made and operated by human beings. Thus, living organisms are characterised by movements which they perform of their own accord.

NUTRITION

Living organisms need **energy** for all their activities. They obtain this energy from their food. Green plants make their food by a process called **photosynthesis**. In this process, carbon dioxide from the air and water from the soil are combined together to form starch with the help of solar energy absorbed by chlorophyll present in their cells. Besides starch, other chemical substances such as fats and proteins are also formed in the living plant cells and they provide the plant with the energy necessary for survival and growth. Animals and non-green plants (such as bacteria and fungi) cannot manufacture food within themselves in this manner [Fig. 1.3]. They consume other animals and plants for food. By means of a complex process within an organism, food is broken down and converted into protoplasm. The new cells made from its protoplasm enable survival and growth. The activity of taking in and converting food into the living protoplasm in cells is called **nutrition**. It maintains the metabolism in living organisms. It should be noted that non-living objects do not require nutrition for their existence.

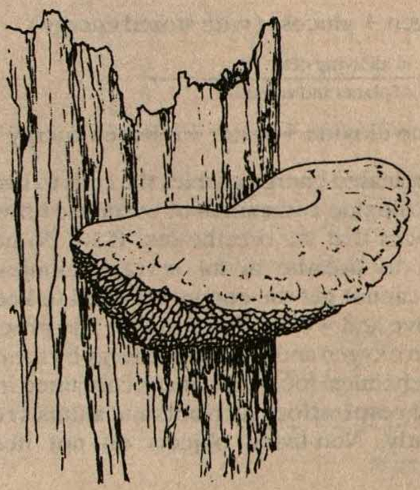


FIG. 1.3 Bracket fungus, a non-green plant, growing on a tree trunk. It feeds on dead or living wood

RESPIRATION

The food that we eat is changed into simple chemical substances in our digestive system. These simple substances are then carried by the blood and **lymph** (an alkaline, colourless fluid, similar to blood plasma) to different parts of our body for the growth and survival of the cells. Next, when we breathe in fresh air, it goes to our lungs. From the lungs, the blood carries oxygen to all the living cells of our body. Plants also breathe in fresh air through small pores in their leaves. Oxygen present in the fresh air reaches all the living cells of the plant through air spaces within the plant. In the living cells of animals as well as plants, the oxygen reacts with the food substances present in the cells. During oxidation of these food substances, such as glucose in the cells of living organisms, energy is released. This is somewhat similar to the release of heat energy from coal when it is burnt. This chemical process of the oxidation of food substances, such as glucose in the living cells, can be represented by the following equation:

$$\text{Oxygen} + \text{glucose (with stored energy)} \xrightarrow[\text{of plants and animals}]{\text{in all living cells}} \text{carbon dioxide} + \text{water} + \text{released energy}$$

The released energy enables the cells to live. The carbon dioxide and excess of water are unwanted substances that we breathe out. If we do not get oxygen to breathe in for several minutes, our bodies cannot get the energy required to keep the cells alive and we are likely to die. The process of taking in oxygen and obtaining energy by the oxidation of chemical food substances contained in cells is called **respiration.** All plants and animals respire constantly. Non-living objects do not need to respire.

Excretion

The metabolism of living organisms involves many other chemical reactions apart from respiration. Just as respiration produces carbon dioxide, these reactions produce substances which are harmful to the life of the cells. In order to remain healthy, all living organisms remove the waste products of metabolism from their bodies. This process is called **excretion.** Non-living objects do not possess metabolism, and, hence, do not excrete.

Definite Shape, Form, and Size

All the organisms belonging to a particular group of living organisms have a definite natural shape, form, and size which may differ within a very narrow range. They also possess the same organs and other physical characteristics. This is why we can distinguish a cat from a monkey and a sunflower from all other flowers in a garden. All men, whether Eurasian, Negroid, or Mongoloid, have the same basic shape and form. It should be noted that there are different varieties of dogs and they differ in height and other features, but all of them have a peculiar characteristic shape and form which enable us to differentiate them from all other animals. On the other hand, no two formations of granite have the same shape and size. In fact, very few non-living objects have a definite natural form.

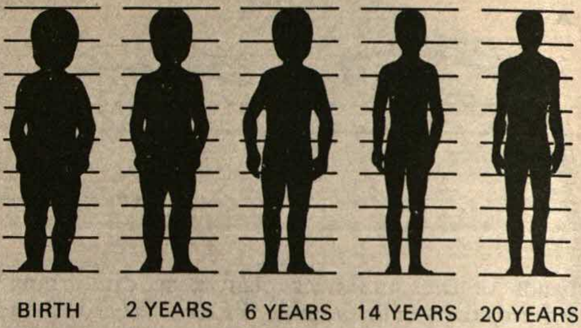


FIG.1.4 The proportions of the various parts of the human body in relation to each other change as the human being grows up. At birth, the head is very large compared to the rest of the body. As the years go by, the limbs grow longer and the torso becomes sturdier. In adulthood, the length of the head is about one-eighth of the body

Growth

We are all born as infants. As the years go by, our limbs increase in size, our bones and muscles become stronger, and our minds develop [Fig.1.4]. Similarly, a small mango sapling grows from a mango seed and develops into a small mango plant and then into a large mango tree.

You may have observed a younger brother or sister, or a pet dog, becoming bigger over the months and years. This process is a part of the process called **growth.** Growth involves building up of new cells and structures within the living organisms—in all plants and animals—and is always internal in all of them. All living organisms use their food to produce new living material—the protoplasm—within their cells and also to form new cells and structures within them. The new cells and structures increase not only the size but also the complexity of the organisms. That is why a full-grown human being has more functions and activities to perform than a child. Some non-living objects also can grow, but their growth is **external.** For example, when a copper sulphate crystal increases in size, particles of this salt are added at the surface of the crystal. This type of growth is temporary and also reversible. If you keep the 'grown-up' crystal of copper sulphate in water, it will start becoming smaller because the extra copper sulphate deposited on the surface will dissolve.

What about nails, horns, and hair? Are these living or dead structures? Don't they also grow?

DEFINITE LIFE CYCLE

During the course of its life cycle, every organism goes through a definite sequence of changes leading to birth, growth, maturity, old age and death. A pea plant begins life when its seed starts forming in the ovary of the flower of the parent plant. Later, i.e., on germination, the pea seed gives rise to a seedling. In the course of a few months, this seedling grows, matures, develops into a plant which bears flowers, fruits, and seeds, and finally perishes. Similarly, a human baby begins its life within the uterus of its mother long before it is actually born. After birth, according to the normal process, a human being grows, matures, reproduces, becomes old, and finally dies. In the course of their life cycle, all living organisms normally produce a new generation of individuals like themselves, which repeat the same life cycle. (Figure 1.5 depicts the life cycle of a toad.)

The average life span of an Indian male is about 50 years, whereas the entire life cycle of a honey bee is completed within a span of 56 days. It should be noted that every species of living organism has a characteristic life span and a life cycle and also that no living species remains alive for ever.

Non-living objects do not have any definite characteristic life cycle and life span.

REPRODUCTION

From the living matter they contain, organisms can create other organisms like themselves. This is a remarkable ability possessed by all living organisms and is called **reproduction.** A simple organism such as *Amoeba* reproduces itself by splitting up into two identical daughter *Amoebae* [Fig.1.6]. A more complicated animal, e.g., a doe rabbit, gives birth to litters of four to eight young rabbits at a time. It should be remembered that an organism of one species can never produce an organism of another species. In this way, each species perpetuates itself by replacing its dead members with new offspring. Non-living objects cannot reproduce themselves. That is why external agents, namely, human beings have to set up steel mills, car factories, and tailors' shops.

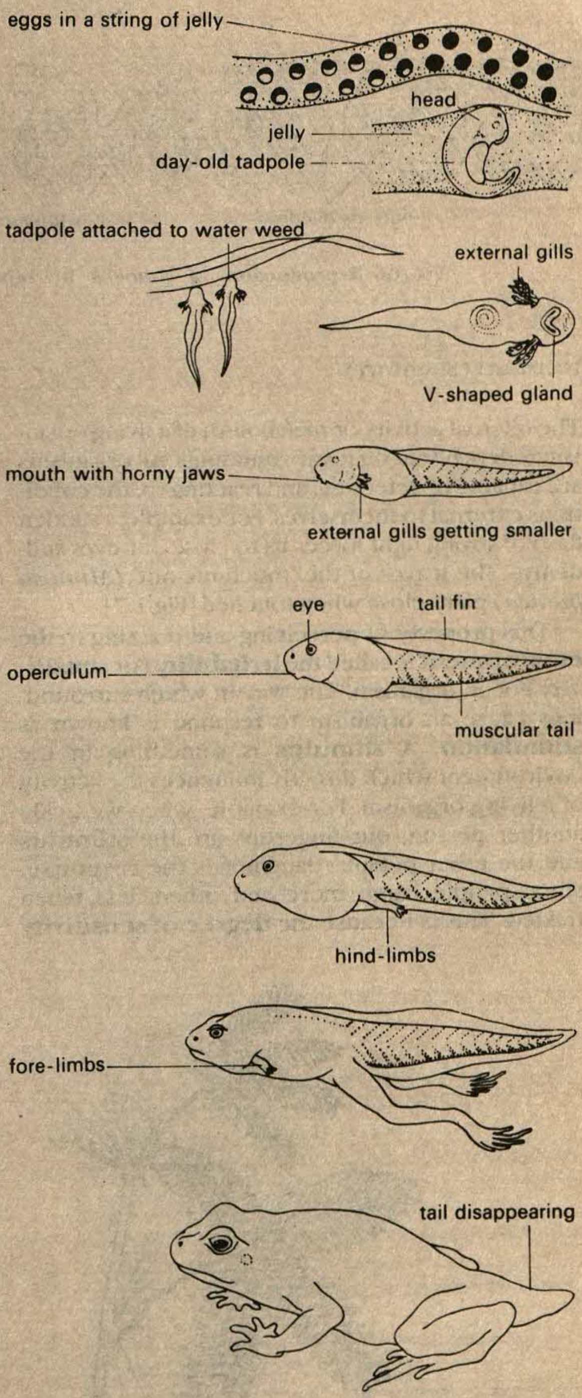


FIG.1.5 Various stages in the life cycle of a toad

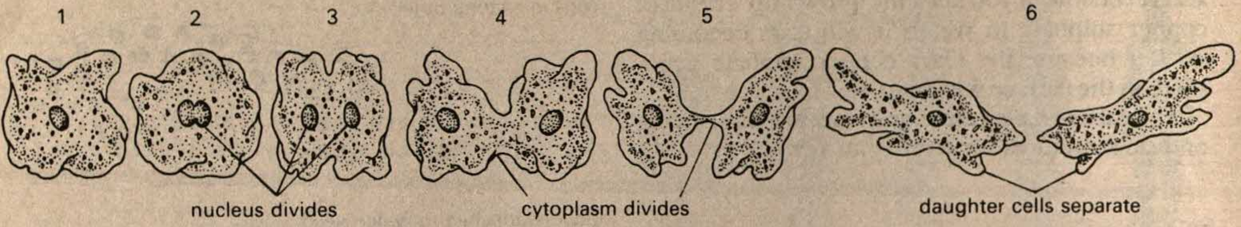


FIG.1.6 Reproduction of *Amoeba* by binary fission, shown in four successive stages

IRRITABILITY (SENSITIVITY)

The internal activity or metabolism of a living organism is dependent on its surroundings. All organisms are capable of detecting, and reacting to, the conditions external to themselves. For example, a sudden flash of strong light forces us to close our eyes suddenly. The leaves of the 'touch-me-not' *(Mimosa pudica)* plant close when touched [Fig.1.7].

This property of perceiving and reacting to the **environment** is called the **irritability** (or **sensitivity**) of an organism. The way in which surroundings cause an organism to respond is known as **stimulation.** A **stimulus** is something in the environment which directly influences the activity of a living organism. For example, when we tickle another person, our fingertips are the **stimulus** and the other person's laughter is the **response.** Some people laugh more and others less, when tickled. This is because the **degree of sensitivity** varies from one person to another. The abovementioned characteristics enable us to distinguish most living organisms from non-living objects. However, many organisms do not possess all these qualities. For example, plants which are rooted in one place cannot move to another place on their own. However, they perform other activities (like growth and reproduction) which only living organisms can. At the same time, some inanimate objects may possess one or more of the above properties. For example, a motor-car may be said to 'feed' on petrol; 'respire' by burning or oxidising it; 'excrete' by expelling smoke; and make use of its released energy for physical movement. Nevertheless, a motor-car cannot move of its own accord. An external force applied by a human being has to start the motor-car. Further, it does not grow or reproduce. Hence, we do not consider it a living organism.

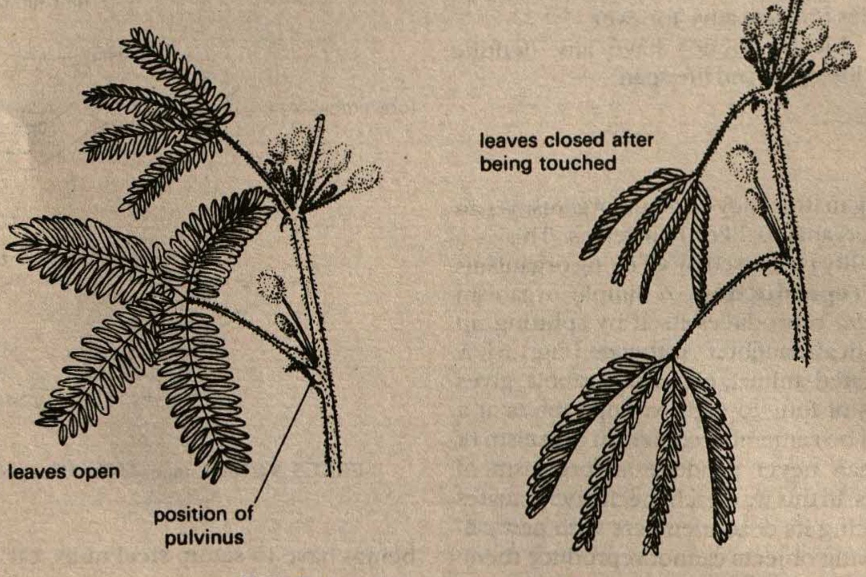


FIG.1.7 Irritability in *Mimosa pudica*

Table 1.1 summarises the major differences between living organisms and non-living objects in order to get a clear-cut picture of the differentiating factors.

TABLE 1.1 SUMMARY OF DIFFERENCES BETWEEN LIVING ORGANISMS AND NON-LIVING OBJECTS

LIVING ORGANISMS	NON-LIVING OBJECTS
1. All living organisms are made of cells which contain the living matter called protoplasm.	Non-living objects are not made of cells.
2. All living organisms have definite body structures or organs, each having a specific function and working in a coordinated manner.	Non-living objects may have different structures or parts, but there is no coordination in the functioning of these parts.
3. All living organisms show movement of different kinds and these movements are of their own accord or due to internal causes.	Non-living objects do not show such movements. They can be made to move only by some external force or mechanically.
4. All living organisms require food from which they obtain energy and with which they build their protoplasm and thus grow.	Non-living objects do not require any food.
5. Metabolism takes place in all living organisms.	No metabolism takes place in non-living objects.
6. All living organisms respire to obtain energy from food.	Non-living objects do not respire.
7. All living organisms excrete in order to throw out the waste and harmful substances formed during metabolism.	Non-living objects do not excrete.
8. All living organisms have definite shape, form, and size.	Non-living objects do not have any definite shape, form and size.
9. All living organisms grow from within by the addition of new living material, protoplasm, formed during metabolism.	Non-living objects do not grow. They may increase in size by the addition of similar substances on their outer surface.
10. All living organisms have a definite life span and go through a sequence of changes leading to birth, growth, maturity, old age and death.	Non-living objects do not have any such life span.
11. All living organisms reproduce their own kind.	Non-living objects cannot reproduce their own kind.
12. All living organisms respond to stimuli.	Non-living objects cannot respond to any stimuli.

EXERCISES

1. Consider a living tree (say, one growing near your house), a dead tree (one which may have been chopped down or which may have been uprooted in a storm), and a table made of wood. Think of five important qualities of each of these, and then make a table comparing the characteristics of these objects. What do you think are the most important distinctions between (a) the living tree and the dead tree and (b) the dead tree and the wooden table?

2. List all the ways you can think of in which you are different from (i) a dog, (ii) a rose bush, (iii) a stone, (iv) an electric fan, and (v) a foreigner, say, an American. Similarly, list all the ways in which you are similar to (i) a horse, (ii) a *pipal* tree, and (iii) your parents.

3. Look up an encyclopedia in your school library and make notes on famous scientists and biologists. For example, you could read about Louis Pasteur, Charles Darwin, Carl von Linnaeus, Robert Koch, Gregor Mendel, Robert Hooke, Sir Gowland Hopkins, Lord Lister, Ivan Pavlov, Beijerink, Buchner, Chamberland, Eijkman, Sachs, and Hargobind Khurana.

4. In the twentieth century, biology has developed so rapidly and extensively that it is no longer considered to be a single science. Among the most important and fascinating biological sciences are microbiology, biochemistry, biophysics, genetics, ecology, and biometry. Consult an encyclopedia to learn something about each of these subjects.

5. Modern computers are used to solve very difficult problems in offices, libraries, and factories. They have been used to plan and control modern spacecraft flights to the moon and the planets of the solar system. Although a computer can 'think' and has a 'memory', why is it not a living organism?

6. (a) What is a cell?
   (b) What are the differences between the movements of a pea plant and a domestic cat?
   (c) Why is nutrition essential for living organisms?
   (d) Give three differences between the burning of a fuel (like coal) and the respiration of living organisms.
   (e) Why do all living organisms excrete?
   (f) On the basis of which characteristic can we distinguish the appearances of a monkey, a sunflower, and a honey bee from each other?
   (g) Define 'growth' and distinguish between the growth of a human being and a calcite crystal.
   (h) What do you understand by the terms 'life cycle' and 'life span'?
   (i) How does a class of living organisms continue to exist even though its individual members die?
   (j) What do you understand by the following terms? (i) environment; (ii) stimulus; (iii) irritability; and (iv) response.

CHAPTER 2

Plants and Animals

Plants and animals are the two groups of living organisms. All plants and animals have all the characteristics of living organisms. However, there are certain differences which enable us to distinguish plants from animals. Some of these are listed in Table 2.1.

TABLE 2.1 DIFFERENCES BETWEEN PLANTS AND ANIMALS

PLANTS	ANIMALS
1. Plants are usually fixed in the soil and cannot move about freely from place to place, except some such as Desmids and Diatoms.	Animals usually move about freely from place to place, except some such as sponges and corals.
2. A majority of the plants are green in colour because they have a pigment called **chlorophyll** in most of their cells, except fungi.	Animals do not have chlorophyll in any of their cells.
3. Plants which have chlorophyll in their cells can manufacture their own food with the help of sunlight by using carbon dioxide from the air and water from the soil.	Animals cannot manufacture their own food. They are dependent upon plants for their food.
4. Plants do not have any special organs for digestion because they manufacture their own food.	Animals have special organs for digestion because they have to take in ready-made food and digest the same.
5. Plants have a relatively low level of organisation and they do not have definite organ systems.	Animals have a high level of organisation and they have definite organ systems such as digestive, respiratory, excretory and nervous systems.
6. Plants have less definite shape and size, except for some lower plants.	Animals have more definite shape and size except some animals such as the *Amoeba*.
7. The plant body is branched except in palms and some lower plants.	Animals do not have branched bodies except for sponges and corals.
8. Plant bodies are of the spreading type to enable them to have large surfaces for absorption of carbon dioxide, oxygen, water, and sunlight.	Animals have compact bodies. This enables them to move about freely from place to place.
9. Plants have special growing regions near the **apices** (tips) of their roots and shoots.	Animals do not have special growing regions. All parts of their bodies grow uniformly, proportionately, and simultaneously.
10. Plants grow indefinitely throughout their lifetime (indeterminate growth).	Animals have a definite growth. Growth stops after a definite body shape and a definite body size have been established. However, their body cells are replaced from time to time (determinate growth).
11. Plant cells have a thick and rigid cell wall of cellulose around their cell membrane.	Animal cells are surrounded only by a cell membrane. They have no cell wall.

PLANTS	ANIMALS
12. Plant cells usually have large vacuoles containing cell sap.	Animal cells usually do not have vacuoles, but, if present, the vacuoles are very small.
13. Plants are usually strengthened and supported by mechanical tissues such as collenchyma, sclerenchyma, and tracheids.	Animals are supported by structures such as bones, cartilage, scales, plates, and shells.

INTERDEPENDENCE OF PLANTS AND ANIMALS

Plants and animals are regarded as the best friends of each other in the true sense of the term. They depend upon each other to fulfil many of their needs, and one cannot survive without the other.

Dependence of Animals upon Plants

(i) Green plants manufacture their own food by **photosynthesis**. They take in simple substances such as carbon dioxide from the air and water from the soil and manufacture carbohydrates in the presence of sunlight. No animal can *manufacture* its own food. In fact, all animals depend upon plants for their food, directly or indirectly. Animals eat either the plants and their products, or other animals and their products, which, in turn, eat the plants. For example, a lion eats the flesh of animals which have fed upon plants.

(ii) During photosynthesis, green plants absorb carbon dioxide (which is harmful) from the air and give out oxygen. Oxygen is essential for respiration of all animals (and also all plants).

(iii) Man (an animal) also depends upon plants for food (vegetables), shelter (timber), clothing (cotton), fuel (firewood, coal, kerosine, and petroleum), and medicines (herbs).

Dependence of Plants upon Animals

(i) Many insects, birds, and other animals pollinate the flowers, which help in the reproduction of plants.

(ii) During respiration, all animals (and also plants) give out carbon dioxide. Carbon dioxide is very essential to green plants for photosynthesis.

(iii) Several animals including birds, bats, and squirrels help in the dispersal of seeds and fruits of plants.

(iv) Animals such as earthworms, rats, and snakes burrow into the soil and make it porous for better growth of plants.

(v) Decomposed and rotten wastes of animals are used by man as fertiliser or manure.

(vi) Man (an animal) plays a very important role in improving the quality of plants through his research and experiments.

EXERCISES

1. What are the ways in which the living organisms are different from non-living objects?
2. What are the main characteristics which distinguish plants from animals?
3. Comment on the statement: 'All flesh is grass.'
4. State the ways in which
   (a) animals are dependent upon plants and
   (b) plants are dependent upon animals.

CHAPTER 3

The Structure of Cells

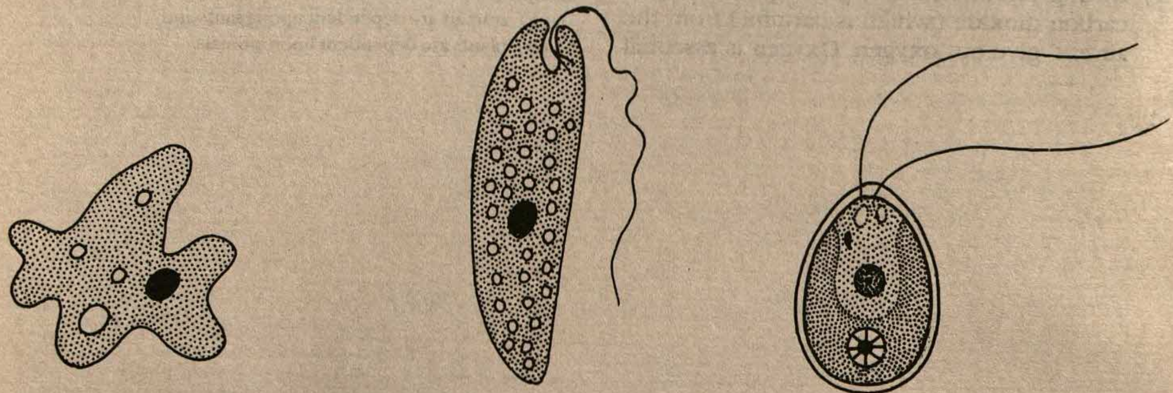
As mentioned in Chapter 1, all living organisms are made up of **cells**, just as buildings are made up of bricks. In other words, all animals and plants are made up of cells. For instance, a human being, a lion, a mango tree, a rose, and a pea plant—all are made up of cells.

The simplest living organisms such as *Amoeba*, *Euglena*, and *Chlamydomonas* [Fig. 3.1 (a-c)] consist of just one cell. Such organisms are known as **unicellular organisms.** Other organisms such as a human being, a pigeon, a snake, a frog, a fish, insects, weeds, bushes, climbers, and trees have numerous cells in their body. These are known as **multicellular organisms**.

In unicellular organisms, all activities and functions of life are carried out by one cell only. In multicellular organisms, several million cells work as a team to carry out the different activities and functions of life.

CELL—A UNIT OF LIFE

A cell is the basic structural and functional unit of all living organisms. It is the smallest unit of all living organisms. Every part of our body such as the hand, the foot, the ear, the eye, the heart, and the stomach, and even the bones, are made up of numerous cells. Similarly, every part of a plant, such



(a) *Amoeba*

(b) *Euglena*

(c) *Chlamydomonas*

FIG. 3.1 Three unicellular organisms

as the root, the stem, the leaf, and the flower, is made up of millions of cells.

A cell can perform all the essential functions of life. It takes in nourishment; it grows; it produces energy to carry out work; and it throws out wastes and unwanted substances formed within it. It can also divide to give rise to two new cells.

Cells were first observed in 1665 by Robert Hooke, an English scientist. He designed one of the earliest optical microscopes [Fig. 3.2]. With the help of his microscope, he examined many objects. While examining thin sections slices of cork, he discovered that cork was made up of numerous **box-like parts. He called these parts cells because they look like a honeycomb.**

The cork examined by Hooke was dead material. Later, Hooke and other scientists examined living materials. They discovered that all of them contained these box-like parts. Gradually, it was established that all living organisms are composed of box-like compartments called cells which are filled with a fluid substance. In 1838, M. J. Schielden and Theodre Schwann put forward the **cell theory**, which states that all plants and animals are composed of cells which are the fundamental structural and functional units of an organism. In 1839, Purkinje coined the term 'protoplasm' for the fluid substance contained in the cells. In 1849, cell division was discovered for the first time. In 1885, Virchow concluded: *Omnis cellula e cellula*, i.e., new cells arise only by the reproduction of pre-existing cells. Today, the views of Hooke, Schielden, Schwann, Purkinje, and Virchow have been accepted internationally.

The original microscope could achieve only limited magnification. Along with scientific progress, several new gadgets were devised for viewing minute objects, among which the electron microscope stands out as a very important instrument [Fig. 3.3]. This microscope can magnify an object several thousand times (more than 200,000 times).

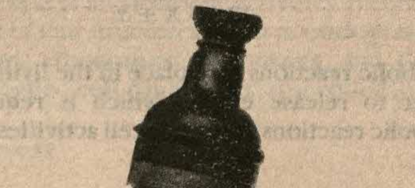


FIG. 3.2 Hooke's compound microscope (A.D. 1665)

PROTOPLASM

Protoplasm is the living material contained within the living cells. All the functions of life take place in

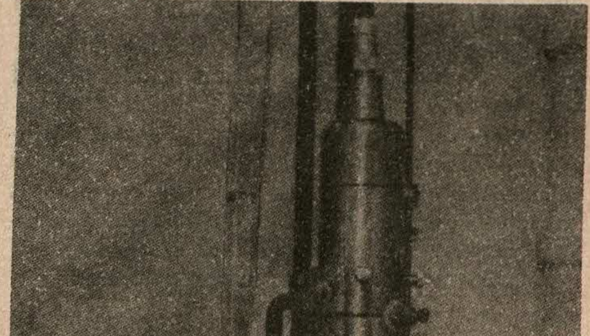


FIG. 3.3 Electron microscope

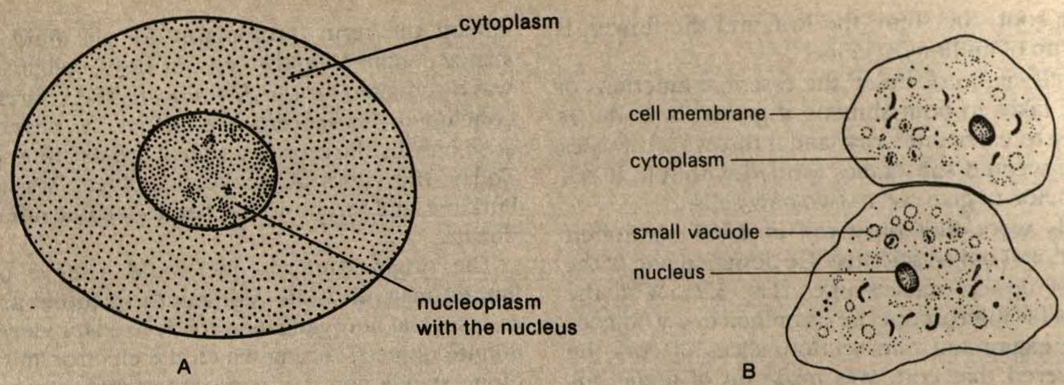


FIG. 3.4 A: General structure of a cell and B: two human cheek cells

the protoplasm. In fact, life depends upon the functioning of protoplasm only. Huxley has called protoplasm 'the physical basis of life.'

In appearance, protoplasm is a translucent fluid. It is either colourless or slightly grey in colour. It is a complex mixture of many chemical compounds. Elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, calcium, and several others combine to form various organic and inorganic chemical compounds present in the protoplasm. Carbohydrates, proteins, fats, and nucleic acids are the chief organic chemical compounds present in the protoplasm. Of the inorganic chemical compounds certain acids, bases, and salts and water are amongst the more important ones.

METABOLISM

Chemical reactions take place in the living cells at all periods of time. The entire series of chemical reactions that take place in the living cells is known as **metabolism.** It is the metabolism which keeps the cells alive and this is the most important characteristic of all living organisms.

Metabolic reactions take place in small steps with the help of biocatalysts called **enzymes.** There are two types of metabolic reactions: **anabolic** (or synthetic) and **catabolic** (or breakdown) reactions. Both these types of chemical reactions take place in the living cells of all animals and all plants at all periods of time.

In anabolic chemical reactions, simple chemical molecules are chemically linked together to form complex chemical molecules:

$$X + Y \rightarrow XY$$

Anabolic reactions result in the building up of living protoplasm and its contents with the help of non-living chemical substances which enter the cells. Carbohydrates, fats, proteins, and nucleic acids are formed due to anabolism. For such building activities, the anabolic reactions require energy.

In catabolic chemical reactions, complex chemical molecules are chemically broken down into simpler molecules:

$$XY \rightarrow X + Y$$

Catabolic reactions take place in the living cells in order to release energy which is required for anabolic reactions and other cell activities.

GENERAL STRUCTURE OF A CELL

The cells in animals as well as plants contain the living protoplasm within them. The protoplasm is always differentiated into two distinct parts [Fig. 3.4]: (a) a dense **nucleoplasm** enclosed within the nucleus and (b) **cytoplasm**, which surrounds the nucleus.

Externally, a cell is bounded by a thin **cell membrane** or **plasma membrane**, which encloses the protoplasm. The cell membrane is a living membrane and is a part of the living cytoplasm. It is present in both plant and animal cells. In plant cells, outside the living cell membrane lies a comparatively thick, non-living wall called the **cell wall.** This wall is made up of a chemical substance called **cellulose**. This cellulose is secreted by the protoplasm of the plant cells [See Figs. 3.5, 3.6, 3.7 and 3.8 for different kinds of cells and their structures].

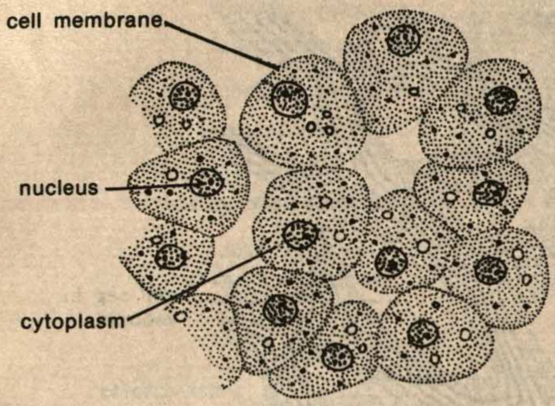


FIG. 3.5 A group of animal cells

CYTOPLASM

Cytoplasm is a complex colloidal suspension of variable density—fluid, semi-fluid, or viscous. It contains substances such as carbohydrates, proteins, fats, mineral salts, vitamins, enzymes, ribonucleic acid, and water. Cytoplasm is generally in an active state of streaming movement. It is considered the seat of all metabolic activities. It contains a number of fine structures (such as **endoplasmic reticulum**, **ribosomes**, **lysosomes**, and **Golgi bodies**), called **cell organelles**, suspended in it.

CELL MEMBRANE

The cell membrane is present in plant cells as well as animal cells. It encloses the cell and controls the movement of various substances entering and leaving the cell.

CELL WALL

The cell wall is a tough and slightly elastic wall present outside the cell membrane only in a plant cell. It helps maintain the shape and form of the cell. It also provides support, rigidity, and protection to the cell.

The line of separation between one plant cell and the other is known as the **middle lamella**. Although each plant cell appears to be enclosed in a box of cellulose, it is not really isolated from its neighbours. There are narrow pores in the cellulose cell walls. These narrow pores have fine strands of protoplasm which join the cells to one another. These strands of protoplasm are called **plasmodesmata** or **plasmodesma** strands. They are thought to help in the movement of materials between the cells. They also help in the thickening of the cell walls.

NUCLEOPLASM AND THE NUCLEUS

The **nucleus** is a dense spherical or oval mass of specialised protoplasm called **nucleoplasm**. Usually, the nucleus lies in the centre of a cell. It is present in the plant cells as well as animal cells. It is bounded by a thin nuclear membrane which separates it from the surrounding cytoplasm. The nuclear membrane controls the movement of vital materials across it from the cytoplasm to the nucleoplasm, and vice versa, i.e., from the nucleoplasm to the cytoplasm.

The nucleus contains a denser body called the **nucleolus**. It also contains small **chromatin** granules which become organised into chromosomes when the cell begins to divide. The nucleus directs and controls all activities of a cell and is also essential for cell division. The nucleolus is composed of ribonucleic acid and is responsible for the formation of ribosomes and nucleoproteins.

CHROMOSOMES, GENES AND DNA

The characteristics of a living animal or plant result from the information passed on from the parents to the offspring through their special cells called **sex cells** or **gametes**. This information is coded in definite structures called **genes** which are located in the **chromosomes** [Fig. 3.9]. The special characteristics such as resemblance between parents and offspring are determined by genes, and it is through the genes that these characteristics are handed over from one generation to the next. The genes contain the information or a set of instructions which tell the organism how to develop and what to do. Genes are responsible for what an organism is and what it does. Genes have a special property of reproducing themselves, or replicating, without losing any of the information they carry.

Genes are made up of a chemical called **deoxyribonucleic acid (DNA)**, and it is this DNA which carries the genetic information or a set of instructions in the form of a code. Another very important function of DNA is to direct the cell as to which proteins and enzymes to make.

CELL ORGANELLES

Cell organelles are fine structures found suspended

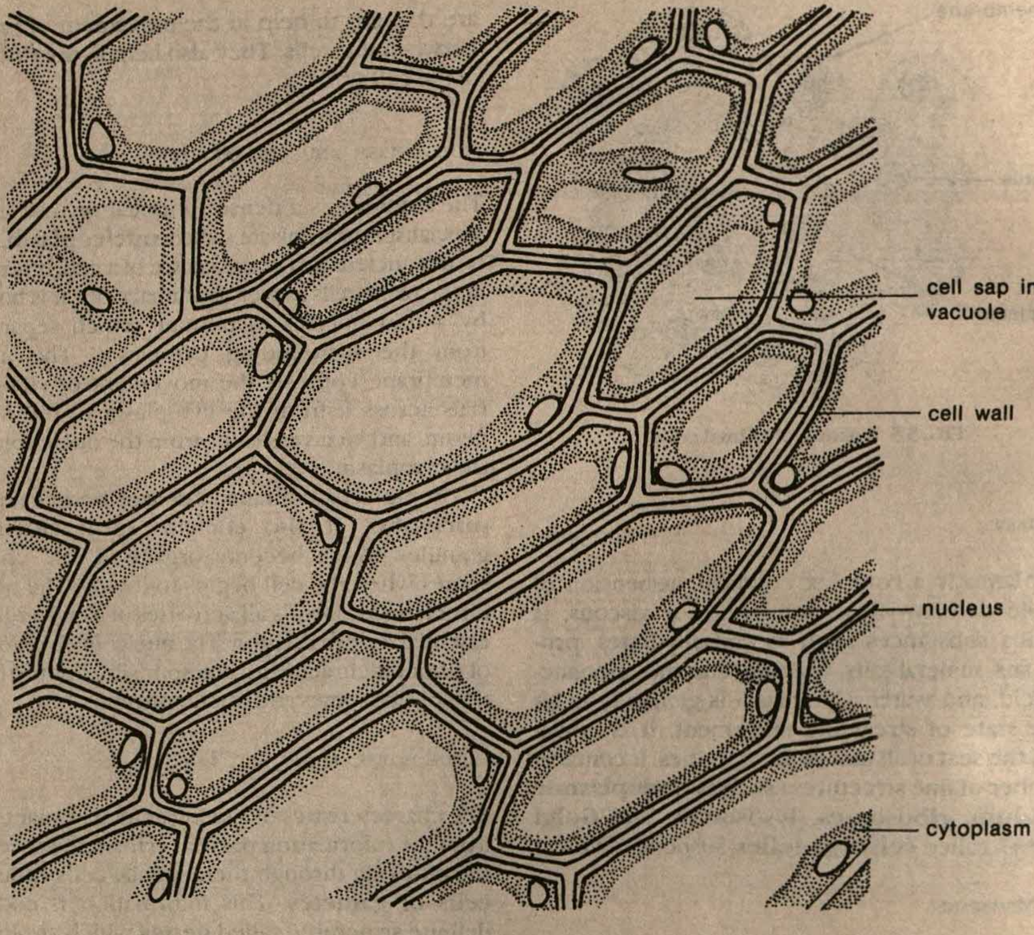


FIG. 3.6 A group of plant cells

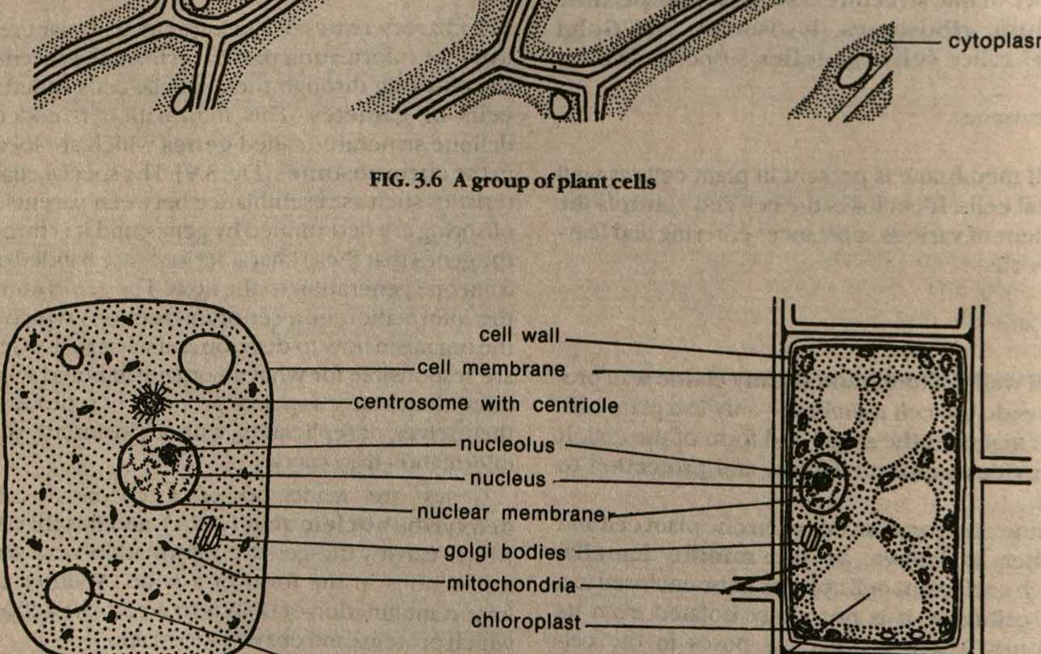
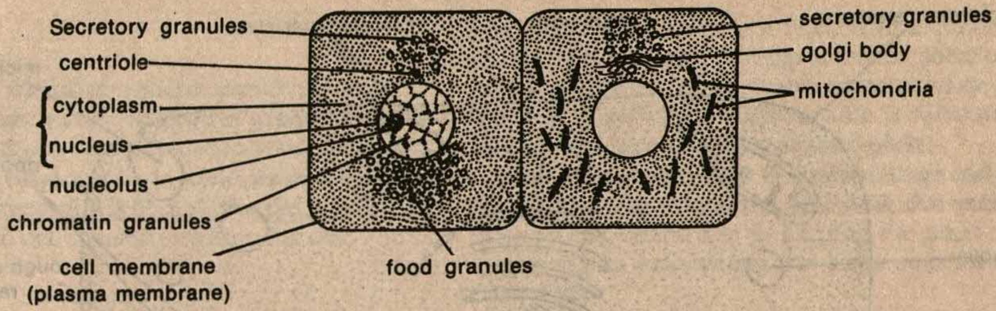
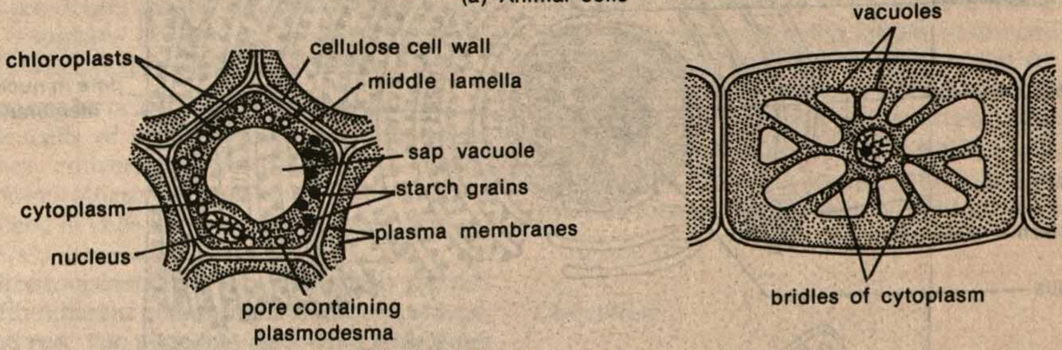


FIG. 3.7 Structure of cells. A: an animal cell and B: a plant cell



(a) Animal cells



(b) Plant cells

FIG. 3.8 Structures of typical animal and plant cells as seen under the light microscope

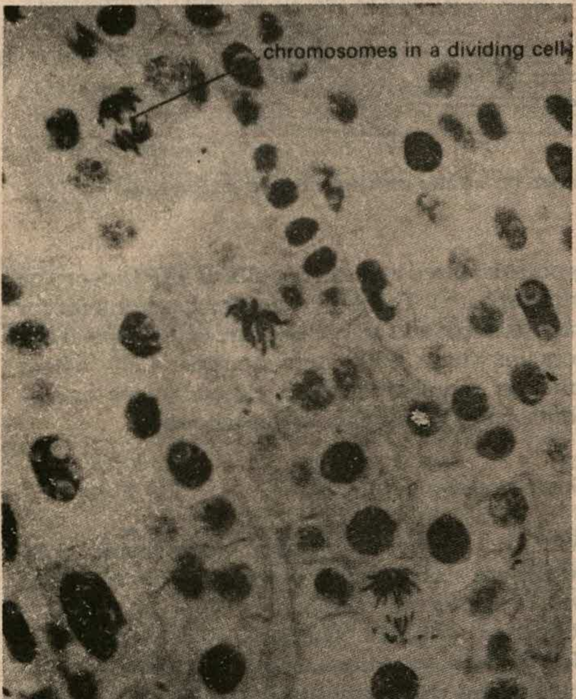


FIG. 3.9 Cells from the tip of an onion root, magnified 400 times. Chromosomes are visible in dividing cells

in the cytoplasm and help in cell metabolism in different ways.

Endoplasmic Reticulum

The cytoplasm consists of a matrix containing a system of flattened cavities, which are nearly parallel to one another. Each cavity is lined by a thin membrane. These cavities are interconnected and their lining membranes are continuous with the nuclear membrane. This system of cavities is called the **endoplasmic reticulum** (**ER**). It is present in both animal as well as plant cells. On the matrix side of most of these cavities are attached the **ribosomes** (described in next section). This ER with the attached ribosomes is called the rough ER. It serves as a network of pathways for the movement of cell proteins such as enzymes and hormones from one part of the cell to another. It also helps in the movement of materials from the nucleus to the cytoplasm and vice versa.

In some parts of the cell, the cavities of ER are without ribosomes. Such an ER is called the smooth ER. It is concerned with the formation and transport of lipids and steroids.

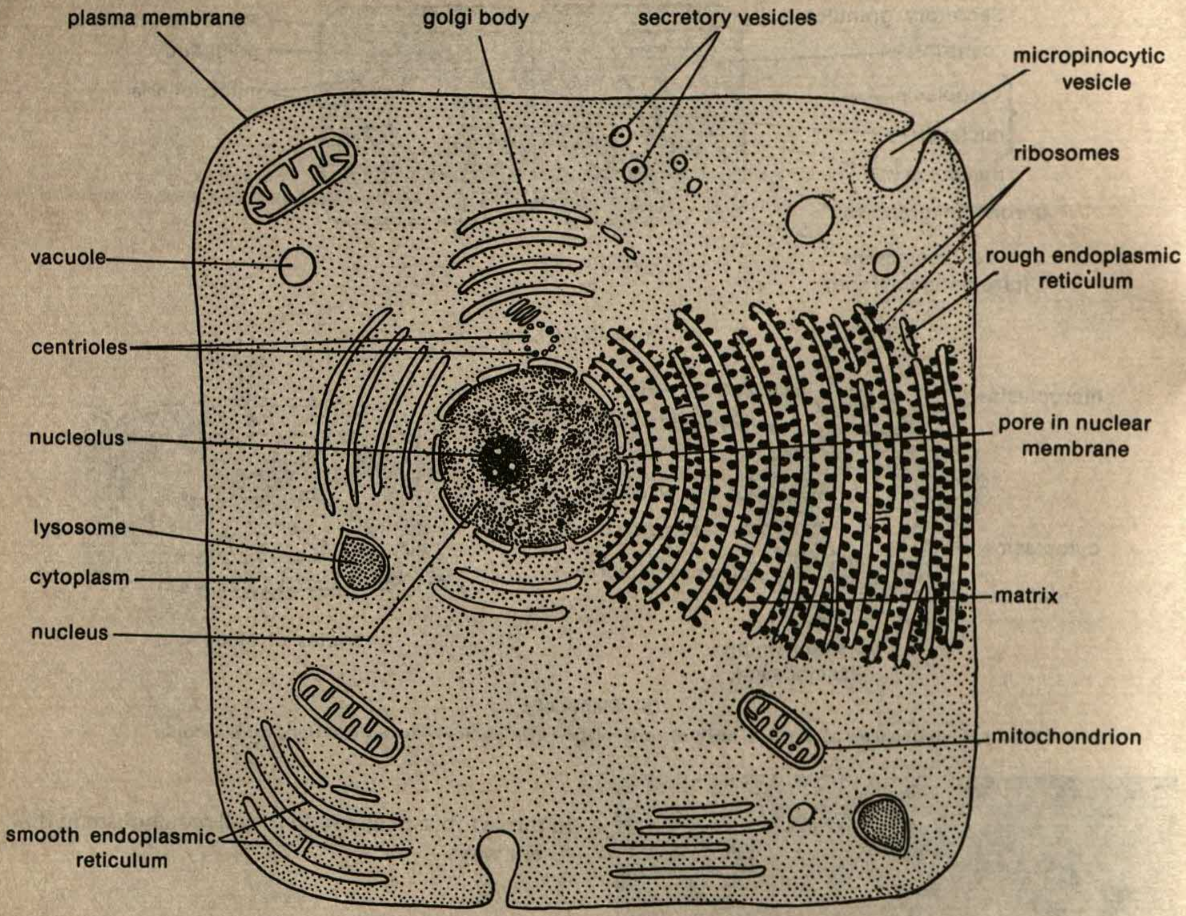


FIG. 3.10 Fine structure of a generalised animal cell based on studies with the electron microscope

Ribosomes

Ribosomes are small granules found freely in the cytoplasm as well as attached to the rough ER [Fig.3.10]. These are manufactured in the nucleolus. Ribosomes are rich in RNA (ribonucleic acid) and are the sites where the proteins are synthesised in a cell. Ribosomes are present in animal as well as plant cells.

Mitochondria

Mitochondria are short rod-like structures scattered all over the cytoplasm in plant as well as animal cells. Cell respiration, by which energy is released to meet the needs of the cell, takes place in the mitochondria. They are, therefore, also called the 'powerhouses' of a cell. The energy released in this process is stored in the molecules of **ATP** (adenosine triphosphate). The stored energy is used later for various needs and activities of the cell. A typical cell contains about 1000 mitochondria. Cells whose function requires them to expend more energy contain a larger number of mitochondria.

Golgi Bodies

With the help of an electron microscope, golgi bodies are seen as stacks of flattened cavities lined with cytoplasmic membranes. These bodies are concerned with the synthesis of cell secretions. Nearly all cell secretions are glycoproteins, i.e., proteins joined with carbohydrates. Golgi bodies add the carbohydrate part to the protein to form the glycoprotein. Golgi bodies are specially prominent in actively secreting cells, particularly gland cells.

LYSOSOMES

Lysosomes are small vesicles (small globular or bladder-like air spaces) which are generally found in animal cells only. Recent evidence has indicated the presence of lysosomes in some plants also. They contain enzymes which destroy the old, worn-out, and unwanted cell structures within the cell.

PLASTIDS

Plastids are dense, usually spherical, bodies found in the cytoplasm of plant cells only. They are centres of chemical activity, and are of three kinds:

(i) **Leucoplasts** are colourless plastids found in the cells of underground stems and roots. They convert the glucose formed during photosynthesis into insoluble starch, which is stored in cells not exposed to light (as in tubers).

(ii) **Chromoplasts** are the pigmented plastids with different colours such as yellow, orange, and red. The pigments associated with them are **xanthophyll** (yellow) and **carotene** (orange .and red). These impart attractive colours to cells, as in the petals of various flowers and the skins of different fruits.

(iii) **Chloroplasts** are the plastids which contain the green pigment called **chlorophyll**. They are found only in those parts of plants that are exposed to light, and are essential for the manufacture of carbohydrates during photosynthesis.

VACUOLES

Vacuoles are bubble-like spaces in the cytoplasm [Fig. 3.10]. Each vacuole is filled with a non-living fluid called **cell sap**. Cell sap is a weak solution of salts and sugars in water. It also contains waste products of metabolism. Each vacuole is surrounded by a **vacuolar membrane** or **tonoplast**.

Plant cells usually have one or two large and permanent vacuoles. Like the cell wall, the vacuole plays an important role in keeping the plant cells turgid and in maintaining the shape and form of these cells.

Animals cells do not usually have vacuoles. If present, these vacuoles are very small and numerous. These are constantly being formed at the cell surface by a process called **pinocytosis**, and are of a temporary nature. Formation of small vacuoles at the cell surface provides an important means by which larger molecules are taken into the cell. It is thought that the large vacuoles present in the plant cells are formed by the fusion of small vacuoles.

CENTROSOME

The **centrosome** is a small area of the cytoplasm near the nucleus. It contains one or two small bodies called **centrioles** [Fig. 3.10]. Centrioles are found in the cells of all animals and also in some algae and fungi. Their main function is to start and regulate cell division in the cells in which they are present.

In addition to all these cell organelles, the cytoplasm may also contain a variety of other inclusions such as food substances, starch, glycogen, fat droplets, proteins, inorganic crystals, and secretory and excretory products formed during cell metabolism.

Table 3.1 summarises cellular structures and functions and Table 3.2 presents the basic differences between animal cells and plant cells.

TABLE 3.1 SUMMARY OF CELLULAR STRUCTURES AND FUNCTIONS

	NAME OF THE STRUCTURE	TYPE OF CELL IN WHICH IT IS PRESENT	FUNCTION
1.	Cytoplasm	Animal and plant	Seat of cell metabolism.
2.	Nucleus	Animal and plant	Control of all metabolic activities and transmission of hereditary characters from parents to offspring, one generation after another.
3.	Nucleoli	Animal and plant	Protein synthesis.
4.	Cell membrane	Animal and plant	Controls movement of material in and out of cell.
5.	Cell wall	Plant only	Protects cell and gives it shape and rigidity.
6.	Endoplasmic reticulum	Animal and plant	Contains enzymes and helps in protein synthesis.
7.	Ribosomes	Animal and plant	Responsible for protein synthesis.

	NAME OF THE STRUCTURE	TYPE OF CELL IN WHICH IT IS PRESENT	FUNCTION
8.	Golgi bodies	Animal and plant	Formation of hormones, storage of proteins and lipids, and secretion.
9.	Mitochondria	Animal and plant	Cell respiration.
10.	Lysosomes	Generally found in animals	Destroy and remove unwanted cell products.
11.	Plastids	Plant only	Storage of starch, seat of colour of plant organs, and also help in photosynthesis.
12.	Vacuoles	Animal and plant	Storage and discharge of excess cell material, and storage of soluble food.
13.	Centrosomes	Animal only	Cell division.

TABLE 3.2 BASIC DIFFERENCES BETWEEN ANIMAL CELLS AND PLANT CELLS

	ANIMAL CELLS	PLANT CELLS
1.	Animal cells are usually small and have a less distinctive outline.	Plant cells are relatively larger and have a more distinctive outline.
2.	Animal cells do not have a cellulose cell wall outside the cell membrane.	Plant cells have a cellulose cell wall outside their cell membrane.
3.	Animal cells usually do not have any vacuoles, but if present, the vacuoles are very small, numerous and of a temporary nature.	Plant cells usually have one or two large and prominent vacuoles of a permanent nature.
4.	Animal cells have lysosomes.	Plant cells do not generally have lysosomes.
5.	Animal cells do not have any plastids.	Plant cells have plastids.
6.	Animal cells have centrosomes, each with two centrioles.	Plant cells do not have centrosomes and centrioles.
7.	Animal cells store carbohydrates, when necessary, in the form of glycogen in the liver and muscle cells.	Plants store carbohydrates in the form of starch.
8.	In animal cells, the cytoplasm fills almost the entire cell.	In plant cells, there is usually a thin lining of cytoplasm.
9.	In animal cells, the cytoplasm is denser and more granular.	In plant cells, the cytoplasm is not very dense and granular.

* Some evidence of the existence of lysosomes has been indicated in plants.

EXERCISES

1. What is metabolism? Where does it take place and why is it important to all living organisms?
2. (a) What do you understand by the following terms? (i) unicellular and (ii) multicellular.
   (b) Give three examples, other than those mentioned in this chapter, of each of the following: (i) unicellular animals; (ii) simple multicellular animals; (iii) simple multicellular plants; (iv) complex multicellular animals; and (v) complex multicellular plants.
3. Draw neat diagrams to distinguish the size of three cells with different shapes and sizes.
4. Describe the following: (a) protoplasm; (b) cytoplasm; and (c) nucleoplasm.
5. (a) What is the nucleus of a cell and where is it generally located?
   (b) Name five structures contained in the nucleus.
   (c) Discuss some of the functions of the nucleus. State briefly why the nucleus is a vital part of a living cell.
6. Using a given model or diagram of a cell, how would you determine whether it belongs to an animal or a plant?
7. Where are the following structures located in a living animal cell? Write your answer in the form of a table: (i) nucleoli; (ii) endoplasmic reticulum; (iii) ribosomes; (iv) golgi

bodies; (v) mitochondria; (vi) lysosomes; and (vii) centrosomes.

8. State the locations and functions of the following structures in a plant cell: (i) cell wall; (ii) cell membrane; (iii) plastids; and (iv) vacuoles.
9. Draw a neat diagram to show the general structure of a cell. Label the diagram clearly and accurately.
10. State the functions of the following: (i) centrioles; (ii) leucoplasts; (iii) chromoplasts; (iv) chloroplasts; (v) enzymes; (vi) DNA; and (vii) genes.

CHAPTER 4

Tissues, Organs, and Systems

In unicellular animals and plants such as *Amoeba*, *Euglena*, *Paramecium* and *Chlamydomonas*, where the body consists only of a single cell, all the basic functions of life are carried out within the single cell. The single-celled body of these organisms is a completely independent unit [Fig. 4.1].

A majority of animals and plants, however, have their bodies composed of numerous cells, i.e., they are multicellular organisms. All of them begin their life as a single fertilised cell which divides repeatedly to give rise to hundreds and thousands of cells. Gradually, these cells become **differentiated** and **specialised** to perform some particular function or functions more efficiently. In the human body and in other multicellular animals and plants, there are numerous different types of cells [Figs. 4.2 and 4.3]. For instance, there are nerve cells which carry messages or impulses from one part of the body to the other; muscle cells which contract and relax and bring about movement; gland cells which produce certain kinds of secretion; red blood cells which carry oxygen from the lungs to all parts of the body; white blood cells which defend the body against microbes; palisade cells which build up starch in plants; epidermal cells which protect the plants from excessive loss of water; root hair cells which absorb water and soluble mineral salts from the soil for the plants; vessels and tracheids which transport

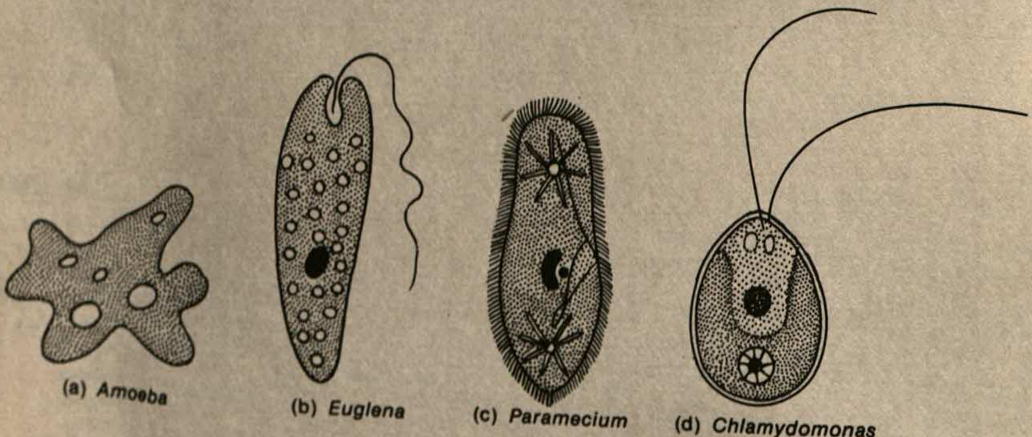

(a) *Amoeba*
(b) *Euglena*
(c) *Paramecium*
(d) *Chlamydomonas*

FIG. 4.1 Some unicellular organisms

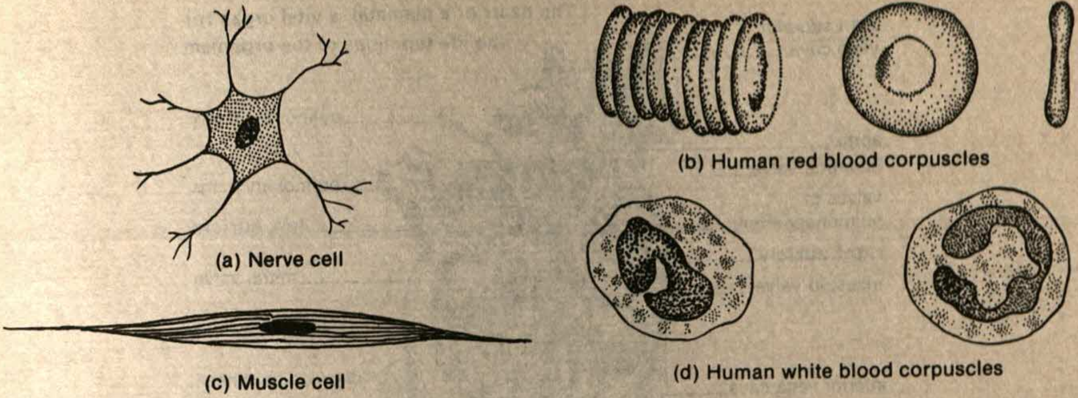

(a) Nerve cell
(b) Human red blood corpuscles
(c) Muscle cell
(d) Human white blood corpuscles

FIG. 4.2 Different types of animal cells

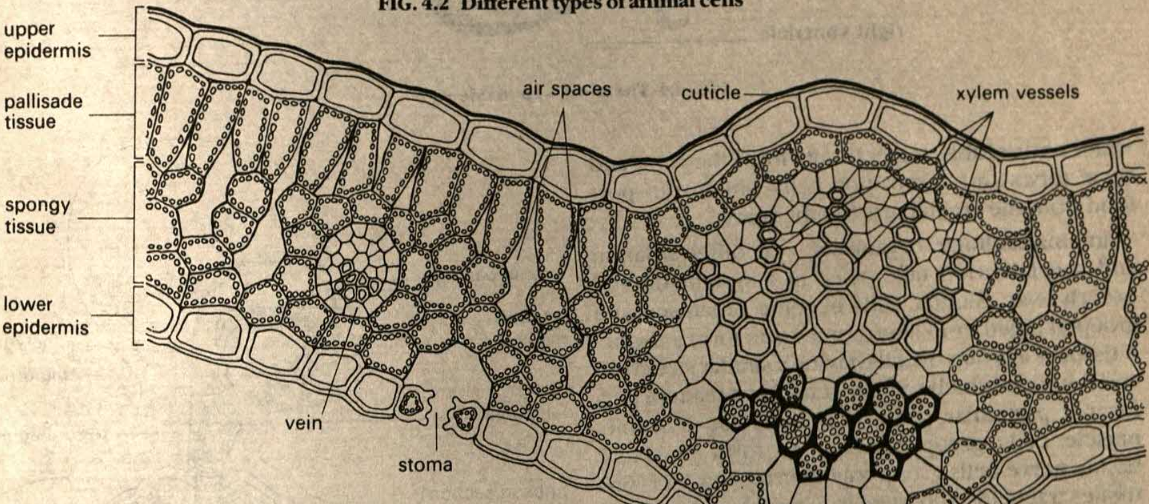


FIG. 4.3 Different types of plant cells

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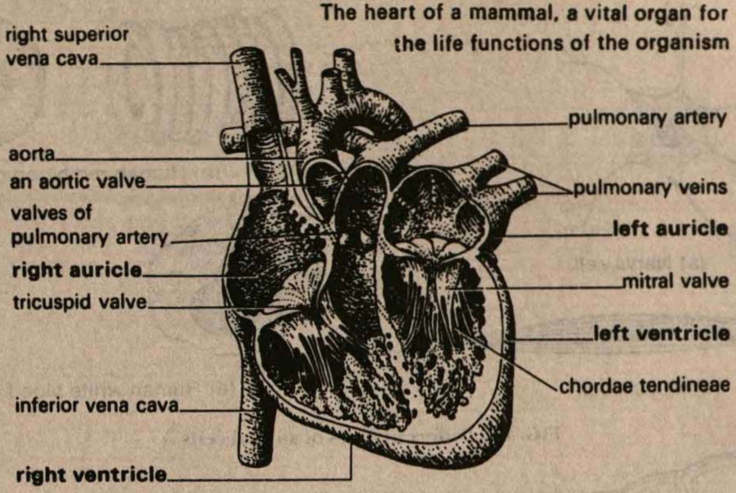

The heart of a mammal, a vital organ for the life functions of the organism

FIG. 4.4 The heart—an inside view

water and soluble mineral salts from the root; and sieve tubes and companion cells which transport food from the green parts to other parts.

In multicellular organisms, cell differentiation and specialisation take place in a systematic and orderly way. Similar cells become organised and grouped together in large numbers to form a **tissue**. A tissue is a group of cells having a similar structure and function which work together as a team to perform a particular group function. For example, muscle cells group together to form muscular tissue; nerve cells group together to form nervous tissue; tracheids and vessels form the **xylem** (the main water-conducting tissue in a plant); and sieve tubes and companion cells form the **phloem** (the tissue conducting sugars, and some amino acids, in a plant)

Several tissues are further grouped together to form an **organ**. Such tissues may be of different types, but they work together to perform some vital function for the entire organism. Some of these organs and their functions are as follows. In animals, the **heart** [Fig. 4.4] for circulating the blood and the **kidney** for eliminating the waste metabolites from the body. In plants, **roots**, for absorbing water and soluble mineral salts from the soil and for fixing the plant, and the **leaf**, for building up starch with the help of sunlight.

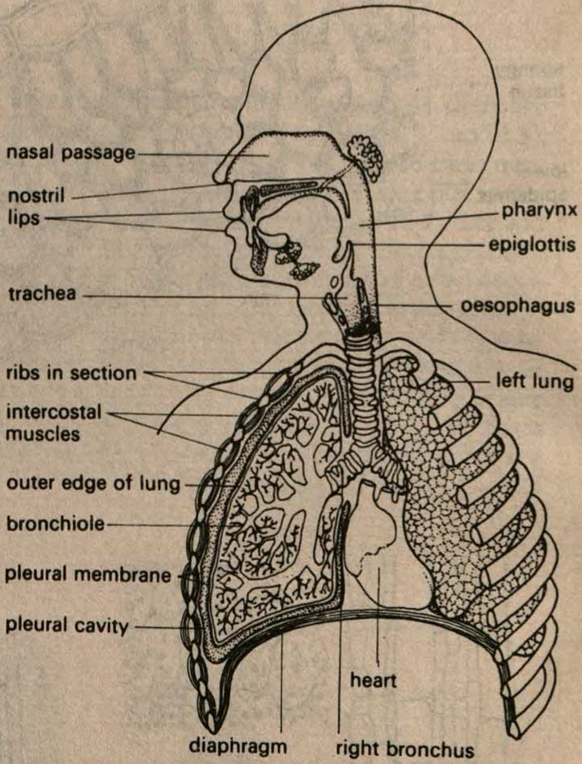


FIG. 4.5 The respiratory system

Finally, when several organs 'cooperate' and function together to perform a major activity of the body, they form an **organ system**, e.g., nostrils, larynx, trachea, bronchi, and lungs, and so on, function together as the **respiratory system** of our body. Next, the mouth, mouth cavity, oesophagus, stomach, intestines, rectum, and so on function together as the **digestive system**. Some of the other organ systems of our body are the excretory system, the circulatory system, the nervous system and the reproductive system [see Figs. 4.5 to 4.9]. In

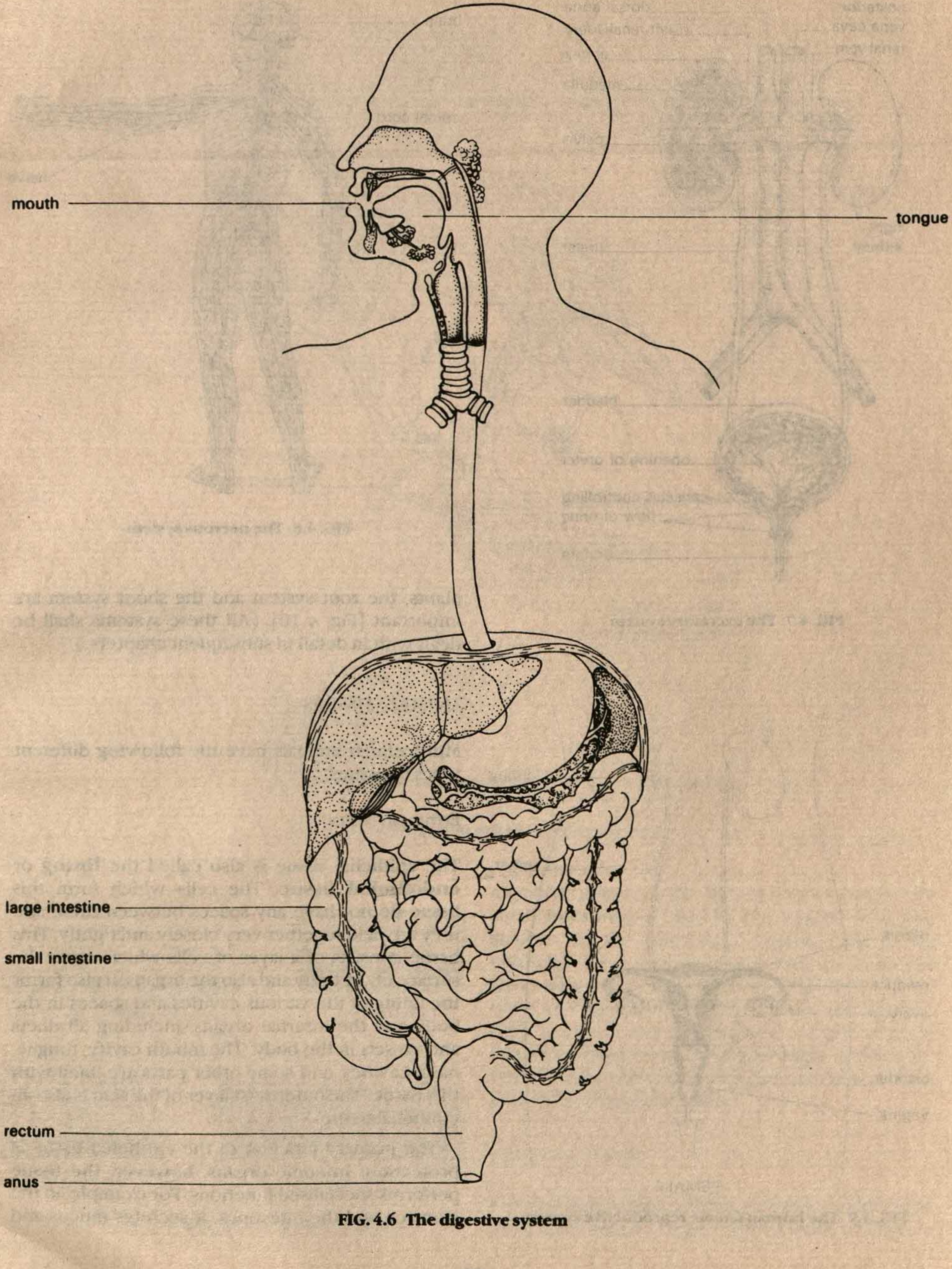


FIG. 4.6 The digestive system

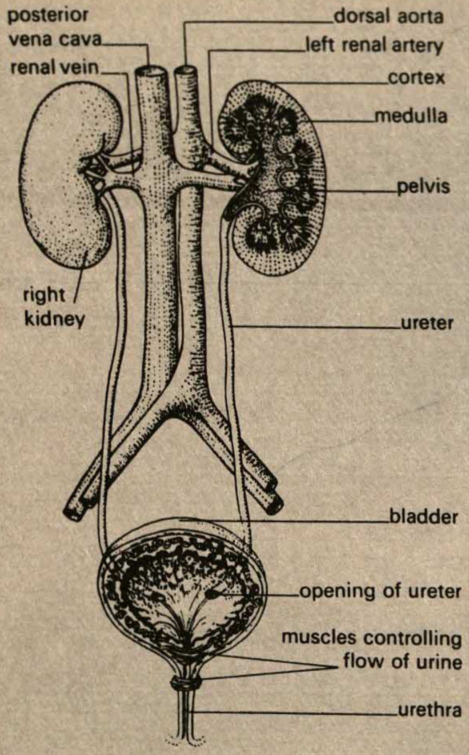


FIG. 4.7 The excretory system

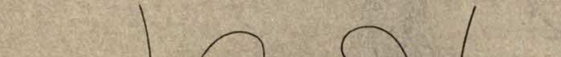


FIG. 4.9 The human female reproductive system

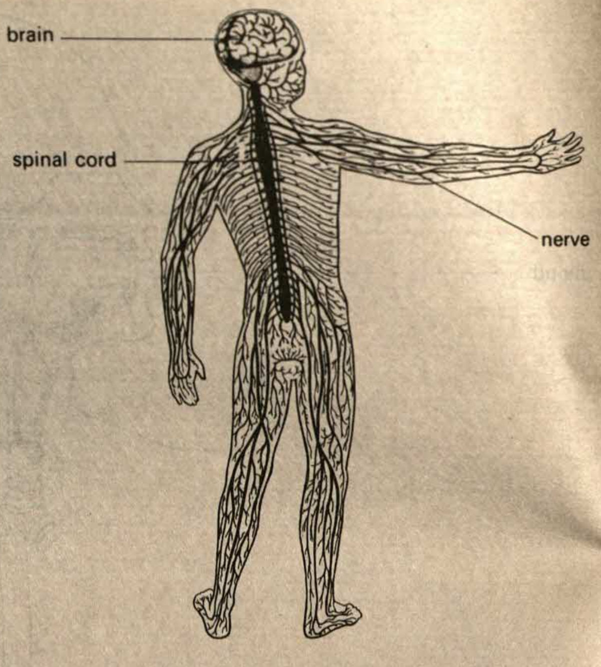


FIG. 4.8 The nervous system

plants, the root system and the shoot system are important [Fig. 4.10]. (All these systems shall be dealt with in detail in subsequent chapters.)

ANIMAL TISSUES

Multicellular animals have the following different types of tissues.

EPITHELIAL TISSUE

The epithelial tissue is also called the **lining** or **endothelial tissue**. The cells which form this tissue do not have any spaces between them and they are held together very closely and tightly. This tissue consists of a layer of cells which cover the surface of the body and also the organs. It also forms the lining of the various cavities and spaces in the body and the internal organs, including all ducts and vessels in the body. The mouth cavity, tongue, nasal cavities, and some other parts are lined with this tissue. The outermost layer of the skin is also an epithelial tissue.

The primary function of the epithelial tissue is protection. In some organs, however, the tissue performs specialised functions. For example, in the stomach and the intestines, it secretes mucus and

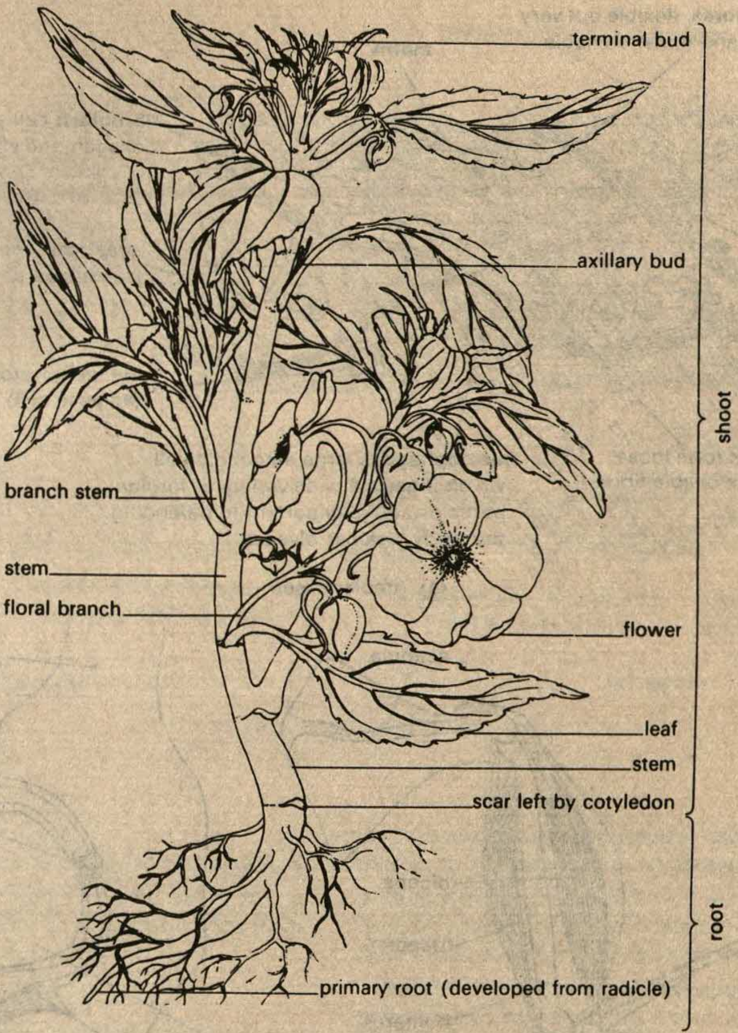


FIG. 4.10 The root system and the shoot system

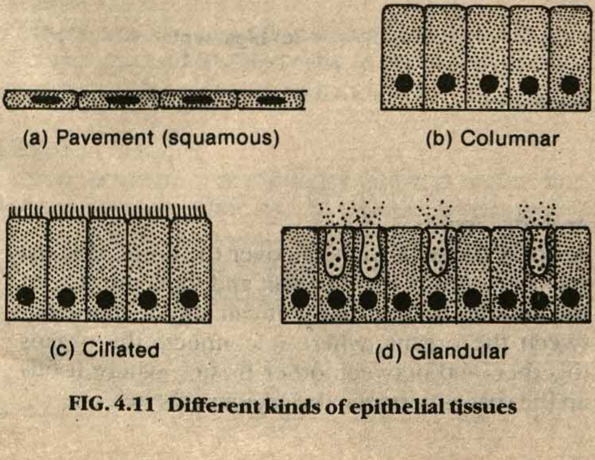
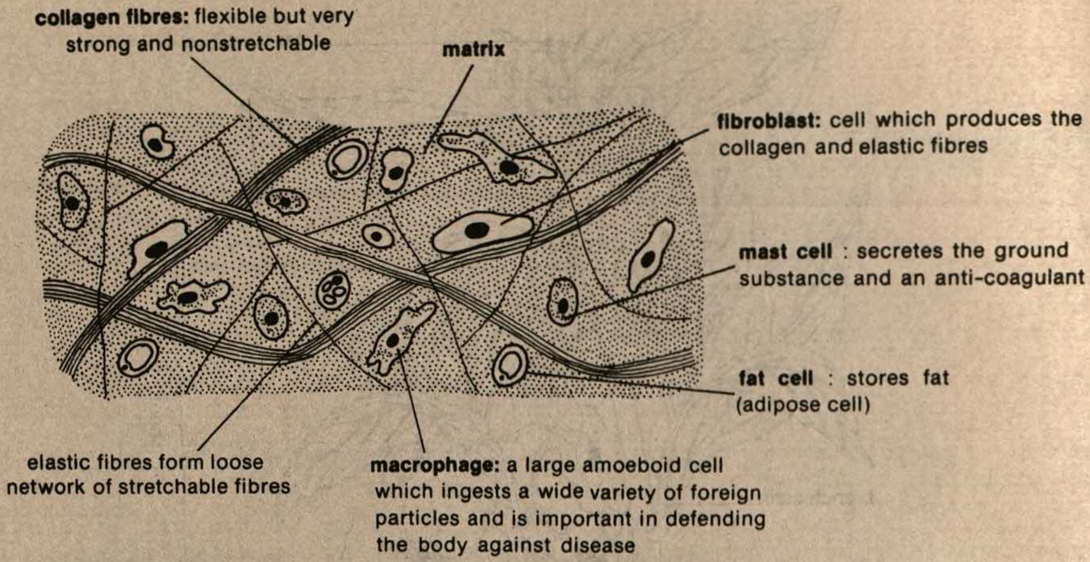


FIG. 4.11 Different kinds of epithelial tissues

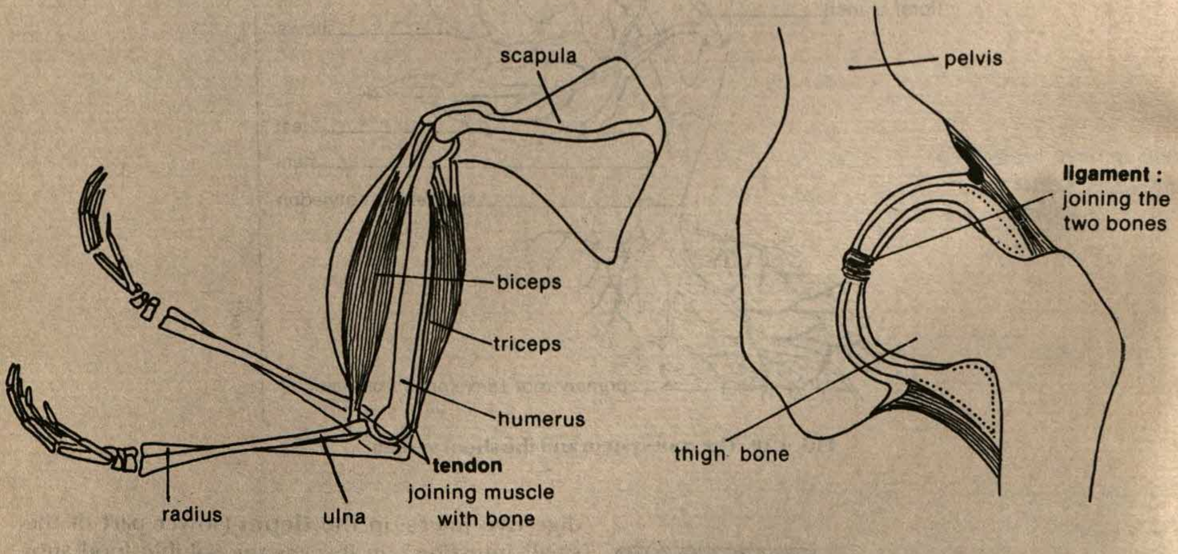
digestive juices; in the **ileum** (lower part of the small intestine), it absorbs the soluble food substances. In the respiratory organs, cells of the epithelial layer secrete mucus and the cells also have **cilia** (hair-like, vibrating outgrowths of the outer cell layer), which beat rapidly and rhythmically to expel small dust particles caught up in the mucus. In the skin, the epithelial tissue consists of a series of protective layers. Figure 4.11 depicts different kinds of epithelial tissues.

CONNECTIVE TISSUE

Connective tissue consists of simple, widely separated cells which contain various fluids or fibres in


collagen fibres: flexible but very strong and nonstretchable
matrix
fibroblast: cell which produces the collagen and elastic fibres
mast cell : secretes the ground substance and an anti-coagulant
fat cell : stores fat (adipose cell)
elastic fibres form loose network of stretchable fibres
macrophage: a large amoeboid cell which ingests a wide variety of foreign particles and is important in defending the body against disease

(a) Areolar tissue


scapula
biceps
triceps
humerus
tendon joining muscle with bone
radius
ulna
pelvis
ligament : joining the two bones
thigh bone

(b) Tendon

(c) Ligament

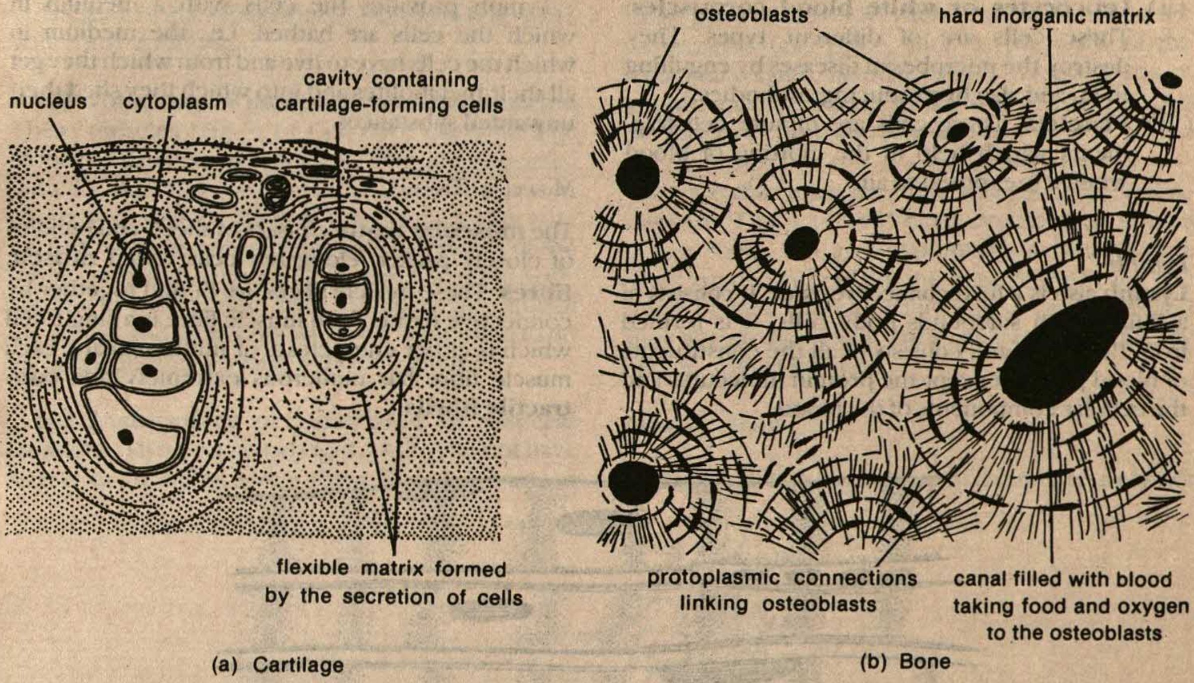
FIG. 4.12 Connective tissues

the matrix or in spaces between them. The different kinds of fibres present in the matrix give it strength and toughness. This connective tissue holds the organs and other tissues together and also provides them support.

Examples of connective tissues [Fig. 4.12 (a–c)] are as follows.

Areolar Tissue

Areolar tissue is found all over the body. This tissue is present below the skin and joins the skin to the muscles underneath it. It can also be found between the organs, where it connects the organs together, and between other tissues, where it fills up the spaces between the adjacent tissues.


nucleus
cytoplasm
cavity containing cartilage-forming cells
flexible matrix formed by the secretion of cells
osteoblasts
hard inorganic matrix
protoplasmic connections linking osteoblasts
canal filled with blood taking food and oxygen to the osteoblasts

(a) Cartilage (b) Bone

FIG. 4.13 Skeletal tissue

Tendons

Tendons are fibrous bands or cords which join the muscles to the bones. Because of the presence of tough and inelastic fibres in its matrix, this tissue has great tensile strength.

Ligaments

Ligaments (fibrous tissue) hold the bones together at the joints. They have elastic fibres in their matrix to give them strength and elasticity.

Adipose Tissue

Adipose tissue (basically a storage tissue) consists of closely packed fat-filled cells. In the dermis of the skin, it provides efficient insulation.

Skeletal Tissue

In basic structure, the **skeletal tissue** is similar to the connective tissue, but its matrix is comparatively hard. It supports the body and provides it with a rigid and strong framework. There are two types of skeletal tissues, namely, **cartilage** and **bone**.

Cartilage: This consists of groups of spherical cells called **chondrioblasts**, which secrete the non-porous matrix. This matrix does not have any blood vessels or nerve fibres, but it may contain elastic or inelastic fibres. Cartilage is found in the nose; ear lobe (pinna); around the trachea and the bronchioles in the form of rings; in between the vertebrae; and at the ends of long bones [Fig. 4.13 (a)].

Bone: This consists of star-shaped cells called **osteoblasts** [Fig. 4.13 (b)]. These cells are arranged in concentric rings. The matrix is porous and contains deposits of calcium salts, mainly calcium phosphate, which make the bones extremely hard. These salts are secreted by the osteoblasts.

Blood

Blood is a fluid connective tissue which circulates in the body. The cells in this tissue are suspended in fluid called **plasma**. The main functions of blood are to transport materials from one part of the body to another and to provide defence against disease and infection.

Blood mainly consists of three types of cells, namely, **erythrocytes**, **leucocytes**, and **platelets** (for further details, see Chapter 20):

(i) **Erythrocytes or red blood corpuscles**: These cells transport oxygen from the lungs to different parts of the body.

(ii) **Leucocytes or white blood corpuscles**: These cells are of different types. They destroy the microbes of diseases by engulfing them and also by producing antibodies.

(iii) **Platelets**: These cells are minute cell fragments which help in the clotting of blood when it is exposed to air.

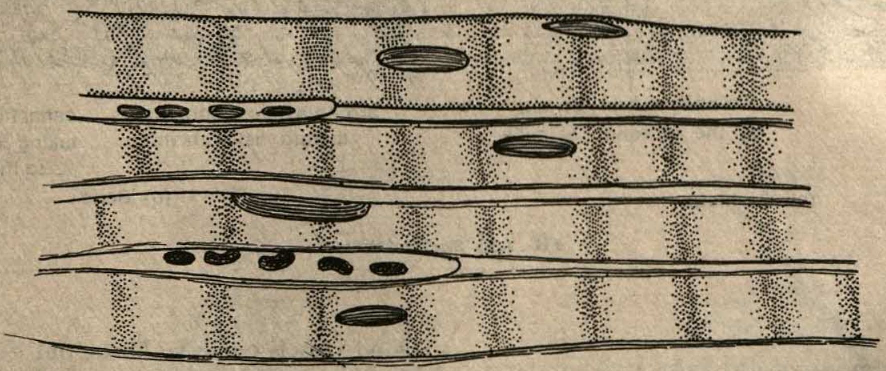
Lymph

Lymph also is a fluid connective tissue. It consists of a fluid which surrounds body cells. It is formed from the blood and consists of all the constituents of blood plasma except the protein molecules and the cellular components of the blood.

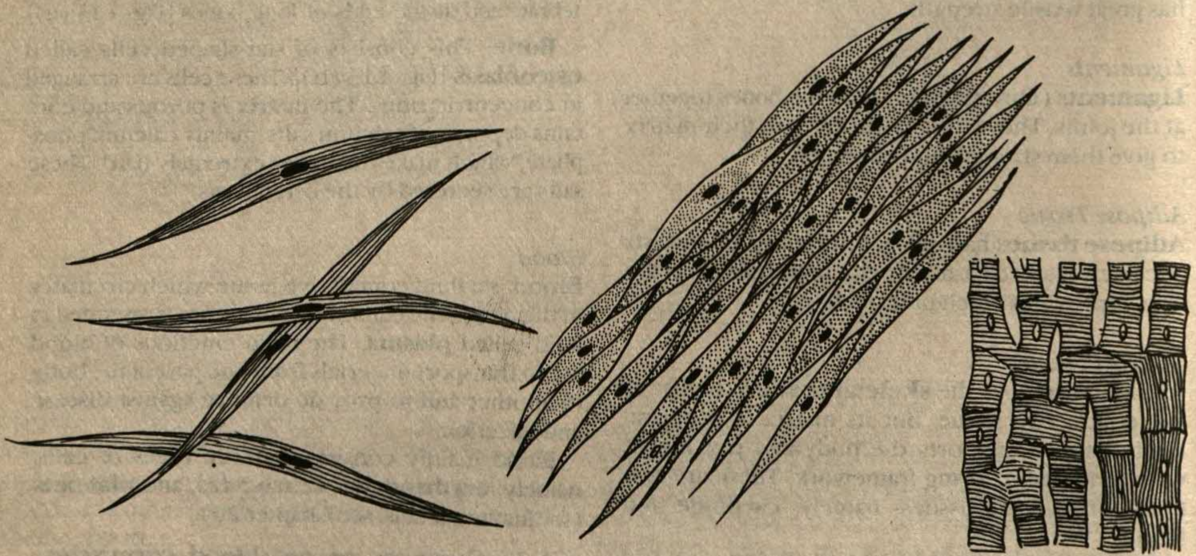
Lymph provides the cells with a medium in which the cells are bathed, i.e., the medium in which the cells have to live and from which they get all their metabolites and into which they shed their unwanted substances.

Muscular Tissue

The **muscular tissue** consists of sheets and bundles of closely packed elongated cells called **muscle fibres**. These muscle fibres are bound together by connective tissue. Each muscle fibre is a single cell which is either uninucleate or multinucleate. Each muscle fibre has numerous extremely fine **contractile fibrils.**



(a) Striated muscles



(b) Unstriated muscles

(c) Cardiac muscles

FIG. 4.14 Muscular tissues

There are three types of muscular tissue [Fig. 4.14], which are as follows.

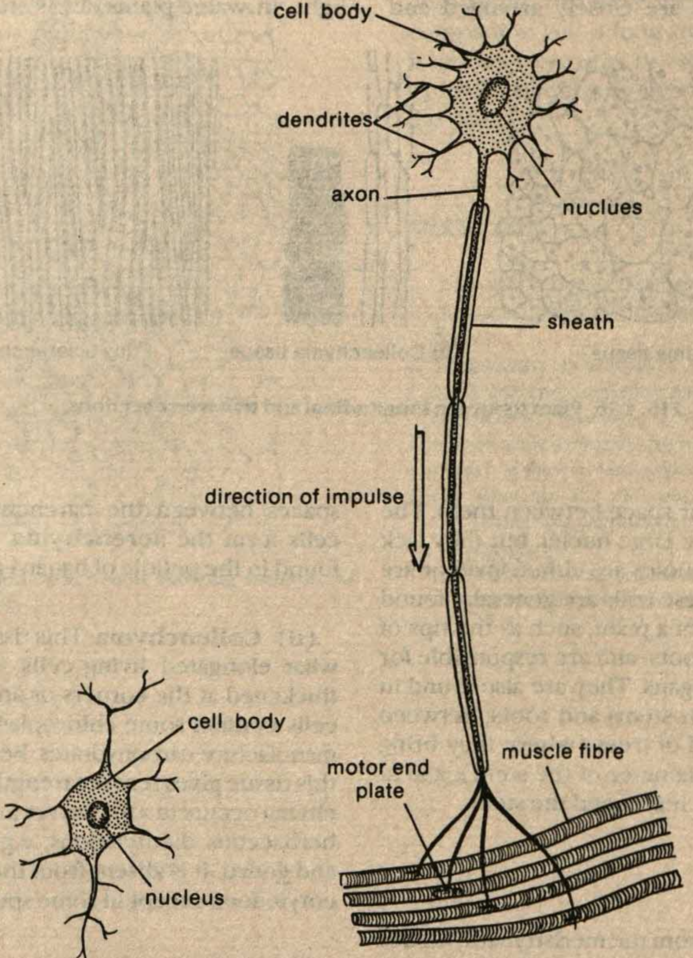
(a) Voluntary or striated or skeletal muscles: These muscles [Fig. 4.14 (a)] have characteristic stripes or striations across them. They are associated with the skeleton and constitute about 50 per cent of our body weight. Further, these muscles are concerned with the locomotion and movement of the limbs. In fact, all voluntary movements in the body are due to their action. They are under the control of our will and work only when we want them to do so. Such muscles get fatigued very rapidly.

(b) Involuntary or unstriated or visceral muscles: These muscles [Fig. 4.14 (b)] do not have stripes or striations across them. They are found in those parts of the body where slow and involuntary movements take place, such as the walls of the alimentary canal, bladder, blood vessels, ducts of glands, and the dermis of the skin. These muscles get fatigued comparatively slowly.

(c) Cardiac muscles : Muscle fibres of the cardiac muscles [Fig. 4.14 (c)] have striations or stripes across them, but are involuntary in their action. They are present only in the walls of the heart. The fibres of these muscles have cross-connections and they appear branched. They contract rhythmically and do not get fatigued.

NERVOUS TISSUE

Nervous tissue is made up of a complex network



(a) Multipolar (b) Motor neuron

FIG. 4.15 Nervous tissue

of interconnected cells known as **neurons**. Such tissue is found in the brain, the spinal cord, and the nerves. Nervous tissue helps in the transmission of **nerve impulses** from one part of the body to another [Fig. 4.15 (a) and 4.15 (b)]. Besides transmitting nerve impulses, the nervous tissue also stores information.

PLANT TISSUES

There are two principal types of plant tissues, namely, **meristematic tissues** and **permanent tissues**.

Meristematic Tissues

Meristematic tissues consist of thin-walled, young and actively dividing cells which constantly form new cells. These cells are closely arranged and there is no intercellular space between them. The meristematic cells have large nuclei, but they lack chloroplasts. Their vacuoles are either small or are completely absent. These cells are generally found at the growing points of a plant, such as the tips of stems, branches, and roots, and are responsible for the growth of these organs. They are also found in the vascular bundles in stems and roots; between the bark and the wood of trees (where they bring about growth in the diameter of the stem); and at the nodes between the leaves and the stem.

Permanent Tissues

The new cells formed from the meristematic tissues gradually grow, get differentiated, and finally mature to give rise to the permanent tissues which perform specialised functions. The cells in a permanent tissue do not possess the property of cell division. These cells may be living or dead.

There are two types of permanent tissues, namely, simple permanent tissues and complex permanent tissues.

(a) Simple permanent tissues: Each such tissue is made up of just one type of similar cells, each having the same structure and functions. There are three kinds of simple permanent tissues, viz., **parenchyma**, **collenchyma**, and **sclerenchyma** [Fig. 4.16].

(i) Parenchyma: This tissue consists of thin-walled living cells. It is found in all the soft parts of a plant. Its main function is to store food, particularly starch. Parenchyma which contains chloroplasts is known as **chlorenchyma**. Chlorenchyma cells manufacture carbohydrates in the presence of sunlight. In water plants, air is stored in the large air spaces between the parenchyma cells and such cells form the **aerenchyma**. Aerenchyma is also found in the petiole of banana and *Canna*.

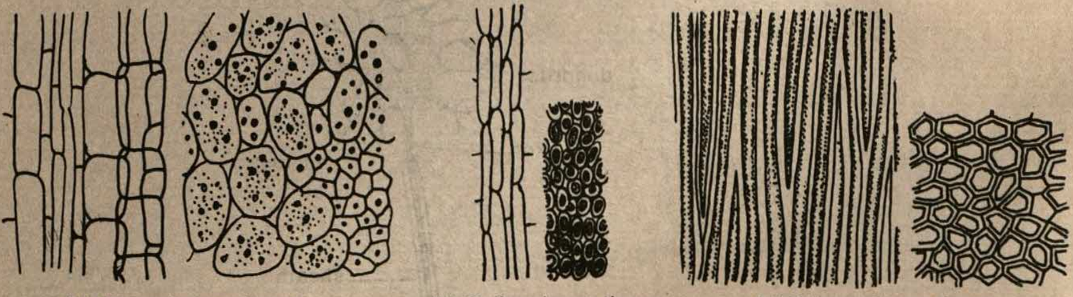

(a) Parenchyama tissue (b) Collenchyma tissue (c) Sclerenchyma tissue

FIG. 4.16 Plant tissues in longitudinal and transverse sections

(ii) Collenchyma: This tissue consists of somewhat elongated living cells. Their cell walls are thickened at the corners or angles. Sometimes, the cells contain some chloroplasts and, as such, they manufacture carbohydrates. Being flexible in nature, this tissue gives tensile strength to the stem. Collenchyma occurs in a few layers under the epidermis of herbaceous dicotyledons, e.g., tomato, sunflower and gourd. It is absent from the root and the monocotyledons except in some special cases.

(iii) Sclerenchyma is a tissue made of thick-walled dead cells. These cells are very long, narrow, and usually pointed at both ends. Therefore, they are known as fibres. Sclerenchyma tissues are present in almost all parts of a plant and give it the rigidity and strength required to withstand various strains. Their average length ranges from 1 to 3 mm, but in some fibre-yielding plants such as hemp and flax, they may reach 20 to 550 mm.

(b) Complex permanent tissues: Each complex permanent tissue is made up of several types of simple permanent tissues. Two kinds of complex tissues, namely, xylem and phloem, are present in the vascular bundles of roots and shoots [Fig. 4.17].

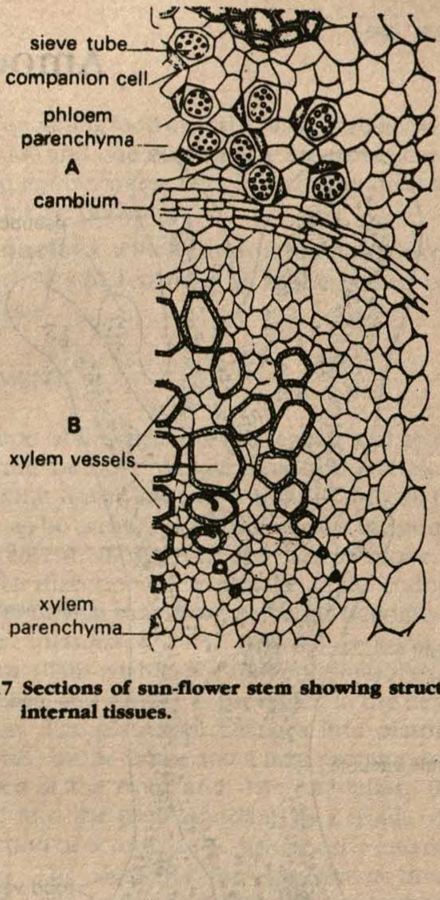


FIG 4.17 Sections of sun-flower stem showing structure of internal tissues.

(i) Xylem is a complex tissue consisting of **tracheids, vessels** and **xylem parenchyma**. Tracheids are dead, elongated cells pointed at both ends, whereas vessels are dead, thick-walled tubes with large cavities. Xylem tissues conduct water and soluble mineral salts from the roots to the leaves, and thus help in nutrition. They also support the body of the plant mechanically. Xylem tissues present in the older parts of a plant form the wood of a tree and do not perform any conducting function.

(iii) Phloem is a complex tissue consisting of narrow, elongated, thin-walled living cells called **sieve tubes, companion cells**, and **phloem parenchyma**. The sieve tubes do not have nuclei and are placed end-to-end. The walls at their narrow ends have holes in them, and are called **sieve plates**. Associated with sieve tubes are companion cells. A companion cell is long and has a spherical nucleus. It helps a sieve tube to conduct food manufactured by leaves to the growing parts and storage organs of the plant.

EXERCISES

1. Why does cell specialisation occur in complex multicellular organisms? Give five examples of specialised cells in your body.
2. What do you understand by 'cell differentiation'?
3. Explain the meaning of the following terms, giving five examples of each: (i) tissue; (ii) organ; and (iii) system.
4. Make a table giving the names, functions, and two examples of each of the four basic types of animal tissues.
5. (a) What are the differences between meristematic and permanent plant tissues? Where are these tissues found in a plant?
   (b) Make a table giving the names, location, and functions of the various permanent tissues found in plants.

Part 2: Simple Forms of Life and the Trend towards Complexity

CHAPTER 5

Amoeba

Amoeba is a unicellular, microscopic, free-living animal found amidst decaying organic matter. It clings to water weeds, stones, and other objects in the mud present in ponds, drains, streams, and ditches. Often, it is also found in the scum on the surface of stagnant water.

STRUCTURE

The *Amoeba* is a mass of jelly-like protoplasm, about 0.25 mm in length. It can be seen only with the help of a microscope. Under a low-power microscope, it appears merely as a translucent mass with an irregular shape. Its detailed structure can be observed only under a high-power microscope. It is then seen to be a single cell [Fig. 5.1].

The cell body is covered by an extremely fine elastic cell membrane or plasma membrane called **plasmalemma**. This is a living cell membrane which controls the movement of material into and out of the body. The plasmalemma surrounds the cytoplasm of the *Amoeba*. The cytoplasm is made up of two distinct regions:

(i) **Ectoplasm**, which is a clear, somewhat thick non-granular cytoplasm lying just inside the plasmalemma.

(ii) **Endoplasm**, which is a greyish cytoplasm consisting of a stiff outer layer called **plasmagel** and an inner fluid called **plasmasol**, in which small granules and globules of food material and metabolic waste are suspended. Also present are several **food vacuoles**

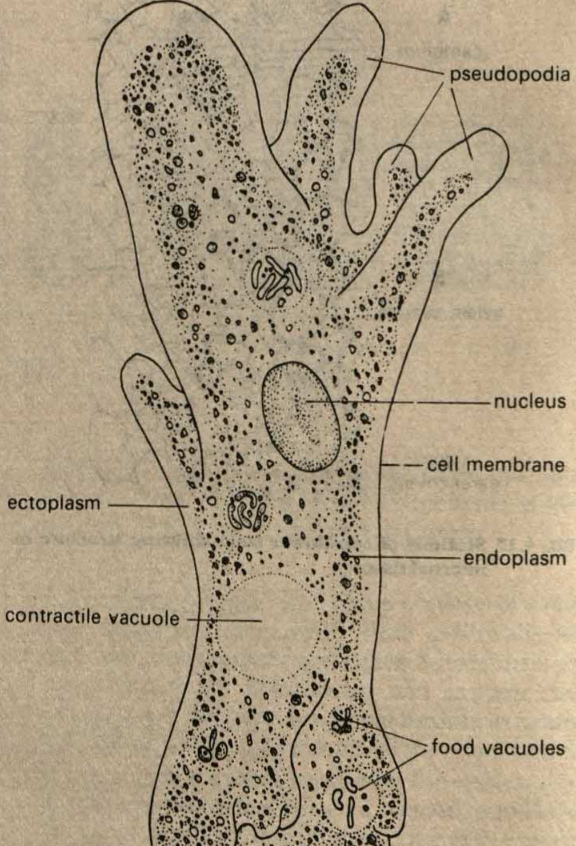


FIG. 5.1 Structure of *Amoeba*

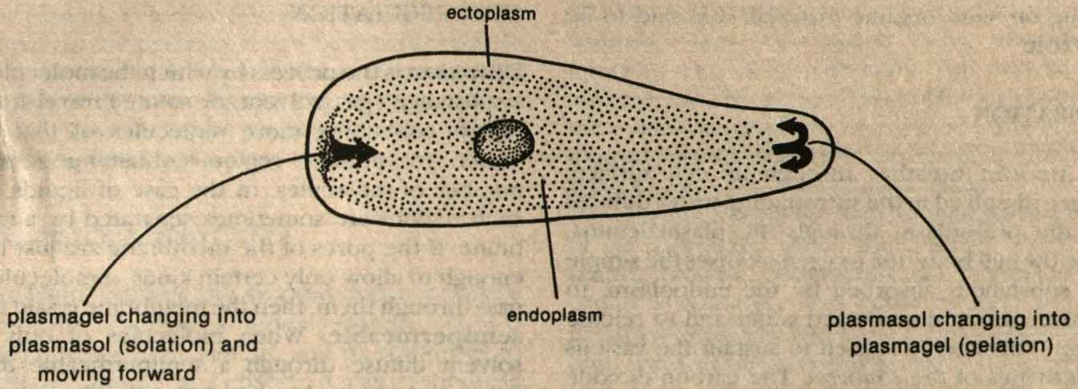

ectoplasm
plasmagel changing into plasmasol (solation) and moving forward
endoplasm
plasmasol changing into plasmagel (gelation)

FIG. 5.2 Amoeboid movement

(containing food material suspended in a watery fluid) and one **contractile vacuole** (containing excess water which has to be discharged from the body).

The **nucleus**, which controls the activities of the *Amoeba*, is situated near or at the centre of the endoplasm.

MOVEMENT

The shape of the *Amoeba* is irregular and changes with time because of **pseudopodia**. These are short, blunt finger-like projections of the cell body which can be created or withdrawn for the purpose of movement. If the *Amoeba* has to move in a particular direction, the plasmagel in the endoplasmic layer on that side of the cell body becomes less stiff, i.e., plasmasol. (The process is known as **solation**.) This enables the inner plasmasol to flow to that side, and a bulge is produced in the desired direction. The plasmasol changes into plasmagel (**gelation**) at the bulge and a new pseudopodium is formed at the front end. The endoplasm flows forward into the pseudopodium as a result of the contraction of ectoplasm at the opposite end of the *Amoeba*. The shape of the *Amoeba* is thereby changed, and its central body of protoplasm is shifted due to endoplasmic flow. The motion produced in this manner is slow, and is called **amoeboid movement** [Fig. 5.2].

NUTRITION

The *Amoeba* feeds on small unicellular plants and animals, such as diatoms, desmids, bacteria, algae, and protozoa, and also on small bits of decayed organic matter. It exercises some choice regarding the materials it takes in; otherwise, it would be overloaded with particles of sand and soil which it constantly encounters.

The *Amoeba* can take in (**ingest**) food at any point on its body surface. When it comes into contact with food material, two pseudopodia are formed to encircle the nutritive particle [Fig. 5.3]. The tips of the pseudopodia meet and form a vacuole which contains the food and also a little water taken in from the surroundings. This vacuole is now enclosed by the endoplasm, which pours enzymes into it to digest the food. The complex nutritive material is broken down into simpler substances which the endoplasm can **absorb**. The absorbed substances are distributed throughout the cell body by means of streaming movements in the protoplasm (via the endoplasmic reticulum). These substances provide the energy required for the functions and the growth of the cell. Undigested or unwanted material is thrown out (**egested**) from any part of the body surface as the *Amoeba* moves. The entire process of nutrition occurs within the cell and is said to be **intracellular**. Since it involves

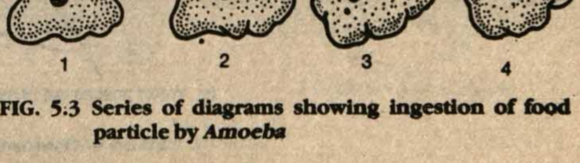


FIG. 5.3 Series of diagrams showing ingestion of food particle by *Amoeba*

feeding on solid organic material, it is said to be **holozoic**.

RESPIRATION

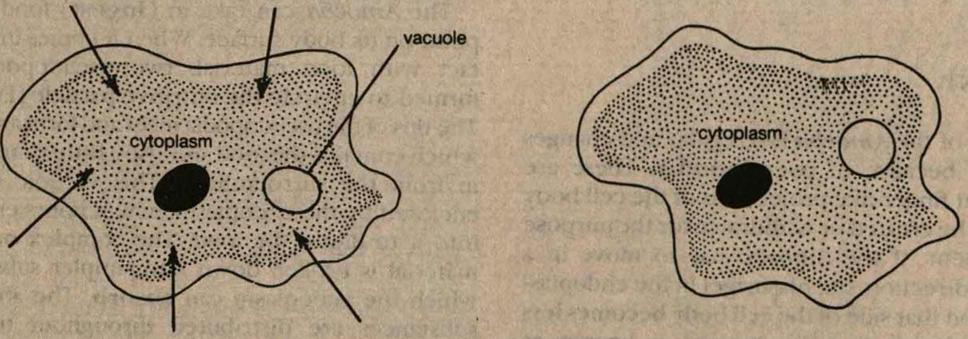
The *Amoeba* breathes through its cell surface. Oxygen dissolved in the surrounding water diffuses into the protoplasm through the plasmalemma. Inside the cell body, the oxygen oxidises the simple food substances absorbed by the endoplasm, to produce carbon dioxide and water and to release energy. This energy is used to sustain the various life activities of the *Amoeba*. The carbon dioxide diffuses out through the plasmalemma into the surrounding water.

EXCRETION

The waste products of metabolism (such as carbon dioxide, urea, and uric acid) diffuse out of the cell through the plasmalemma into the surrounding water.

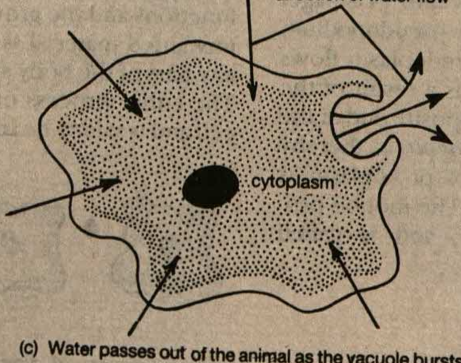
OSMOREGULATION

Diffusion is the process by which the molecules of a substance (gas, solvent, or solute) travel from a region containing more molecules of that substance to another region containing a lesser number of molecules. In the case of liquids, two such regions are sometimes separated by a membrane. If the pores of the membrane are just large enough to allow only certain kinds of molecules to pass through them, then the membrane is said to be **semipermeable**. When molecules of only the solvent diffuse through a semipermeable membrane, the process is called **osmosis**. Plasmalemma is a semipermeable membrane, and molecules of the water surrounding the *Amoeba* are constantly entering the cell by osmosis. If water is allowed to collect in the cell body, the latter would burst. So, the *Amoeba* collects the excess water in its **contractile vacuole**. The vacuole gradually expands as more water enters, and travels to the surface of the cell, where it bursts and throws the excess water out of the body through a small pore formed in the



(a) Water diffuses into the animal by osmosis

(b) Water collects in the vacuole which increases in size



(c) Water passes out of the animal as the vacuole bursts

FIG. 5.4 Osmoregulation in *Amoeba*

plasmalemma. This does not allow any excess water to remain in the cell body. A new contractile vacuole is formed in the *Amoeba* each time an old one bursts, and the cell lives on. This process of regulation of the water content in the *Amoeba* is called **osmoregulation** [see Fig. 5.4].

IRRITABILITY (SENSITIVITY)

Unlike higher animals, the *Amoeba* does not possess either sense organs or a nervous system. Yet, it is sensitive to its environment, and its responses to stimuli are simple and direct. It can distinguish between food particles and sand particles (or other obstacles). It keeps away from both strong light and complete darkness and moves towards diffused light. It is sensitive to temperature and is most active at 20–25°C. If pricked by a needle or pin, it moves away from the point. It avoids contact with chemical stimuli such as common salt, acetic acid, and cane sugar. If an electric current is passed through the water in which it is present, the *Amoeba* withdraws all its pseudopodia and becomes globular. If the current is strong and constant, it moves towards the cathode and finally disintegrates.

REPRODUCTION

The *Amoeba* reproduces in different ways under different circumstances. These different processes are now described.

BINARY FISSION

This is an asexual method of reproduction which occurs only when plenty of water and food are available to the young *Amoeba*. At the beginning of this process, the *Amoeba* withdraws most of its pseudopodia and becomes somewhat rounded [Fig. 5.5]. It then develops many short and blunt new pseudopodia. Next, its nucleus elongates and divides into two daughter nuclei by a process called **mitosis**. These two nuclei move towards the opposite ends of the cell body. This movement is accompanied by an elongation of the cell body, and the cytoplasm gradually narrows down in the middle and gets divided. Thus, two daughter *Amoebae* are formed, each containing a daughter nucleus. The original contractile vacuole is contained in one of the halves; the other half develops a new contractile vacuole. Pseudopodia are formed in each daughter *Amoeba*. This entire process is called **binary fission** and is completed in less than half an hour. Each daughter *Amoeba* feeds on its own, and thus grows, and attains its full size in about 72 hours. It is then ready for binary fission again.

MULTIPLE FISSION AND ENCYSTMENT

These processes occur when the *Amoeba* does not get enough water and food and when the temperature of water is low. If the pond or ditch in which the *Amoeba* lives dries up, it withdraws its pseudopodia, becomes rounded, and secretes a protective covering (called a **cyst**) around itself. The cyst is a three-layered envelope which protects the *Amoeba* from drought. This process of the formation of the cyst is known as **encystment**. In the encysted condition, the *Amoeba* may be still in the dried up pond or may be blown away by the wind to new places (dispersal). Some of these perish, but the ones that reach another pond can begin their life again. During encystment, the nucleus often divides into several daughter nuclei; each of these is surrounded by a little mass of cytoplasm and several *Amoebulae* or **pseudopodiospores** are produced. When moisture is again available to these encysted forms, the following activities take place: The moisture diffuses through the cyst; the living protoplasm becomes active again; the cyst bursts; and pseudopodiospores emerge. The *Amoebulae* feed and grow to attain full size, and each *Amoebula* can reproduce by binary fission (under favourable conditions) or by encystment and multiple fission

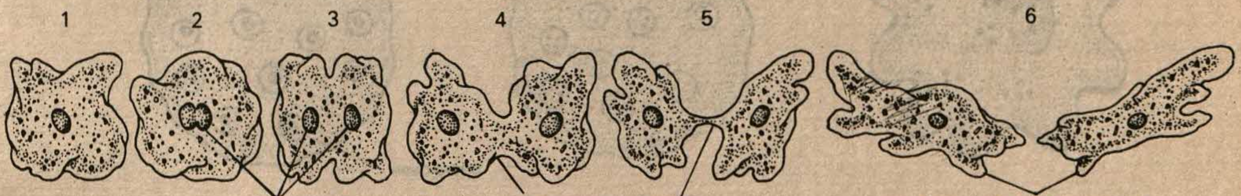


FIG. 5.5 Five stages in the binary fission of *Amoeba*

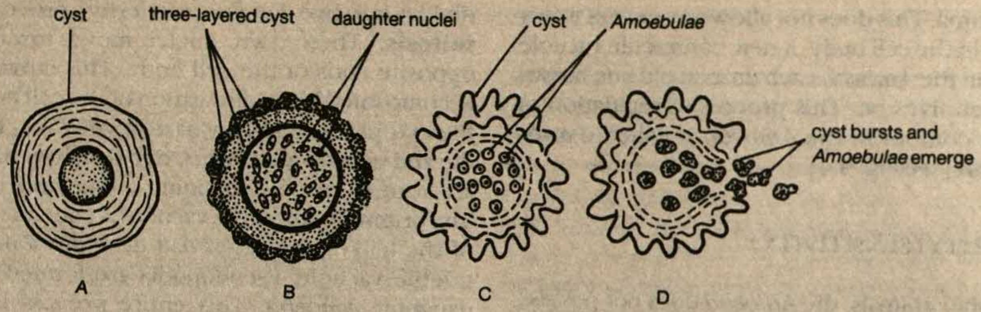


FIG. 5.6 ***Amoeba*: Multiple fission**

(during drought). Encystment is not only a means of protection against drought, but also one of reproduction and dispersal [Fig. 5.6].

SPORULATION

Sporulation is the process by which old *Amoebae* reproduce when they have lost the power of binary fission after several months of existence. In this process, the material of the nucleus gets distributed in small portions throughout the endoplasm of the aged *Amoeba*. A small mass of cytoplasm surrounds each such portion to form a **spore**. Hundreds of spores are produced within the parent *Amoeba* in this way, each one having its own thick covering called a **spore case** [Fig. 5.7]. Gradually, the parent body disintegrates, setting free the spores, which flow away in the surrounding water. These spores are drought-resistant, and break out of their cases, when conditions are favourable, to become small, independent *Amoebae*. Each new *Amoeba* feeds, grows up to its full size, and reproduces by binary fission.

From the above account, it is evident that the *Amoeba* does not die, even if the conditions of life are not favourable. When it is young, it undergoes binary fission. When the conditions of life are not favourable, it undergoes encystment and then multiple fission. After several months of active life, when it becomes 'old', it reproduces by sporulation. There is thus no natural death due to old age as in other living organisms we see around us. In this sense, the *Amoeba* is said to be 'immortal'. However, death may occur accidentally or by other means.

EXERCISES

1. Draw a large, neat diagram of the *Amoeba* and label the following structures: (i) plasmalemma; (ii) ectoplasm; (iii) endoplasm; (iv) pseudopodia; (v) contractile vacuole; (vi) nucleus; and (vii) food vacuoles.
2. (a) What are the functions of the plasmalemma?
   (b) How do plasmalemma, ectoplasm, and endoplasm function to enable amoeboid movement?

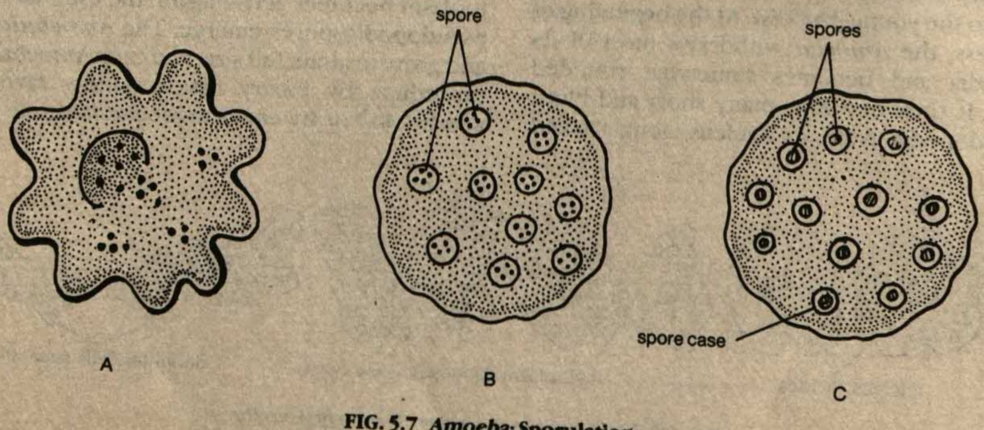


FIG. 5.7 ***Amoeba*: Sporulation**

3. (a) What does the *Amoeba* feed on?
   (b) Describe how the *Amoeba* ingests a food particle. Draw a series of simple diagrams to support your description.
4. How does the *Amoeba* respire and excrete?
5. (a) Briefly define the following terms: (i) diffusion; (ii) semi-permeable membrane; and (iii) osmosis.
   (b) What is osmoregulation, and how is it achieved in the *Amoeba*?
6. Make a table to show how the *Amoeba* reacts to the following stimuli: (i) a sand particle; (ii) strong light; (iii) moderate diffused light; (iv) the point of a fine needle; (v) an electric current passed through surrounding water; (vi) a drop of soda water; (vii) acids, common salt, and sugar; and (viii) temperature between 20°C and 25°C.
7. (a) Describe the following modes of reproduction of the *Amoeba*, stating the conditions under which they occur: (i) binary fission and (ii) multiple fission.
   (b) When does sporulation occur?
   (c) On what basis can we claim that the *Amoeba* is immortal?

CHAPTER 6

Spirogyra

Spirogyra is a simple, multicellular green plant (alga) commonly found in still-water ponds, slow-running streams, and ditches. It looks like a mass of tangled filaments with air bubbles in between, and is slimy to touch.

STRUCTURE

Spirogyra consists of a single row of cells forming a thread-like body called a **filament** [Fig. 6.1]. Each filament is 80–160 mm in length and, under a microscope, is seen to be made up of similar cylindrical cells placed end to end [Fig. 6.2].

Each cell is about 0.75 mm long and has a thick cell wall of cellulose. Outside the cellulose is a covering of **mucilage**, which is a smooth, jelly-like substance that makes the entire plant body slippery. Inside the cell wall is a layer of living cytoplasm which encloses a large central vacuole containing **cell sap** (a solution of minerals in water) [Fig. 6.1]. The nucleus may either lie in the cytoplasm or it may be suspended in the central vacuole by fine cytoplasmic strands. Within the nucleus lies a denser body called the **nucleolus**.

Spirogyra performs the functions of a plant by means of **chloroplasts**. These are present in the cytoplasm in the form of one or two strap-like spirals with smooth or wavy edges. On these spiral straps are found colourless patches which are

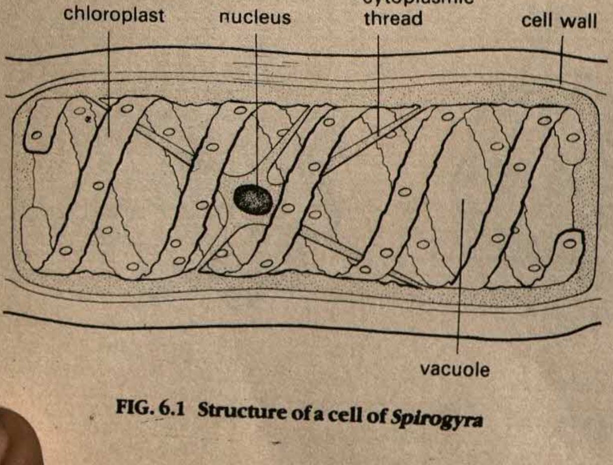


FIG. 6.1 Structure of a cell of *Spirogyra*

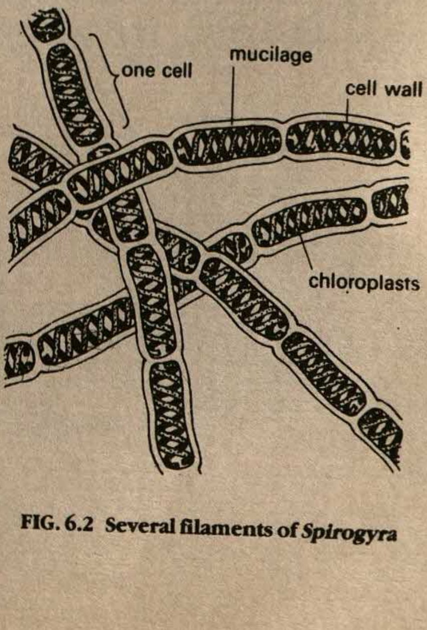


FIG. 6.2 Several filaments of *Spirogyra*

dense bodies called **pyrenoids**. They contain proteins and store food in the form of grains of starch around them.

Each cell in *Spirogyra* has the same structure and can independently perform all the essential functions of life (nutrition, growth, reproduction, etc.). There is no differentiation or cell specialisation. Therefore, *Spirogyra* may be regarded as only a collection or colony of independent unicellular organisms held together in a **mucilaginous sheath** after cell division.

GROWTH

Spirogyra grows only in length, and not in width or thickness. The cells of the filament divide by transverse division of its cells. Growth takes place when the nucleus in a cell in the filament divides. After this, a new cell wall develops across the centre of the parent cell, and each half gives rise to a daughter cell. Each new cell becomes longer till it attains the size of a full-grown cell in the filament.

NUTRITION

Spirogyra produces its own food with the aid of the chloroplasts present in each of its cells. It absorbs water (containing dissolved carbon dioxide) from its surroundings and uses it to manufacture simple carbohydrates (sugars) in the presence of sunlight by **photosynthesis**. The carbohydrates are then used to produce nutrients such as starch and proteins.

RESPIRATION AND EXCRETION

The cells of *Spirogyra* respire by absorbing water from its surroundings. Oxygen is dissolved in this water, and is used to oxidise sugars stored in the cytoplasm. The unwanted carbon dioxide produced during respiration, and the waste products of metabolism, are expelled by diffusion through the cell walls.

REPRODUCTION

Spirogyra can reproduce itself in the two ways described as follows.

First, **vegetative reproduction** takes place by means of **fragmentation.** A filament of *Spirogyra* breaks up into fragments, each of which grows up to the length of a mature filament by the process of cell division.

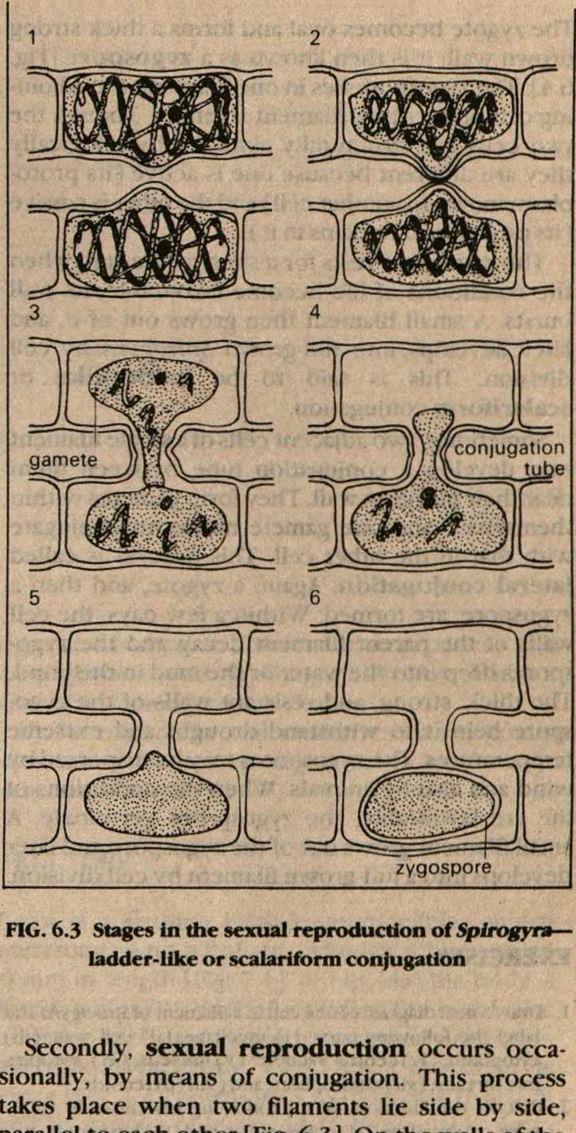


FIG. 6.3 Stages in the sexual reproduction of *Spirogyra*—ladder-like or scalariform conjugation

Secondly, **sexual reproduction** occurs occasionally, by means of conjugation. This process takes place when two filaments lie side by side, parallel to each other [Fig. 6.3]. On the walls of the cells of each filament, tube-like projections appear and grow till they meet. At their point of contact, the cell walls dissolve, leaving a passage called a **conjugation tube** leading from one *Spirogyra* to the other. Thus, two cells from the two filaments are connected.

While the conjugation tube is being formed, the protoplasm in each of these two cells separates from the cell wall and gradually forms a rounded mass called a **gamete**. The gamete of one filament flows through the conjugation tube to meet the gamete in the cell of the other filament. The protoplasts of these two gametes come together and fuse to form a single mass of protoplasm called a **zygote**.

The zygote becomes oval and forms a thick strong brown wall; it is then known as a **zygospore** [Fig. 6.4]. The zygospore lies in one filament; the adjoining cell of the other filament is empty. Though the two cells are structurally similar, physiologically they are different because one is active (its protoplasm moves to another cell) and the other is passive (its protoplasm remains in it).

The zygospore rests for a short while, and when the conditions of life become favourable, its wall bursts. A small filament then grows out of it, and later develops into full-grown *Spirogyra* by cell division. This is said to be **ladder-like** or **scalariform** conjugation.

Sometimes, two adjacent cells of a single filament may develop a conjugation tube between them near their partition wall. They form gametes within themselves, and one gamete moves to conjugate with that in the other cell. This process is called **lateral conjugation**. Again, a zygote, and then a zygospore, are formed. Within a few days, the cell walls of the parent filament decay and the zygospores drop into the water or the mud in the pond. The thick, strong, and resistant walls of the zygospore help it to withstand drought and extreme temperatures. The zygospores may be dispersed by wind and also by animals. When the conditions of life are favourable, the zygospores germinate. A small filament grows out of the zygospore and later develops into a full-grown filament by cell division.

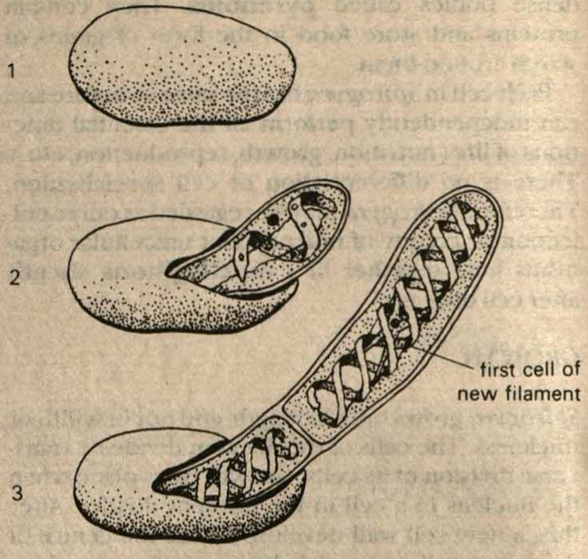


FIG. 6.4 Germinating zygospore of *Spirogyra* in three stages

EXERCISES

1. Draw a neat diagram of one cell in a filament of *Spirogyra* and label the following parts: (i) mucilage; (ii) cell wall; (iii) cytoplasm; (iv) central vacuole; (v) nucleus; (vi) cytoplasmic threads; (vii) chloroplasts; and (viii) pyrenoids.
2. Discuss the functions of the following structures in *Spirogyra*: (i) mucilage; (ii) chloroplasts; and (iii) pyrenoids.
3. Why is *Spirogyra* considered to be only a colony or collection of single cells?
4. How does *Spirogyra* grow?
5. How does *Spirogyra* obtain food?
6. There are two essential requirements for respiration. What are they and how does *Spirogyra* fulfil them?
7. (a) Name the two modes in which *Spirogyra* can reproduce.
   (b) How does vegetative reproduction occur?
8. (a) Draw a series of simple diagrams to show the various important stages in the sexual reproduction of *Spirogyra*.
   (b) What are the following? (i) gamete; (ii) zygote; (iii) zygospore; (iv) active cell; (v) passive cell; and (vi) conjugation tube.
   (c) Differentiate between scalariform conjugation and lateral conjugation.
9. (a) Mention five similarities between *Amoeba* and *Spirogyra*.
   (b) In what way is *Spirogyra* more complex than *Amoeba*?

CHAPTER 7

Hydra

In *Amoeba*, we saw how a single cell lives on its own. In *Spirogyra*, we observed a set of cells working independently, each performing all the essential functions of life. In *Hydra*, one of the simplest multicellular animals, we shall now see how different types of cells are coordinated to form a single organism. In *Hydra*, differentiation produces **cell specialisation**, and physiological division of labour takes place among various tissues.

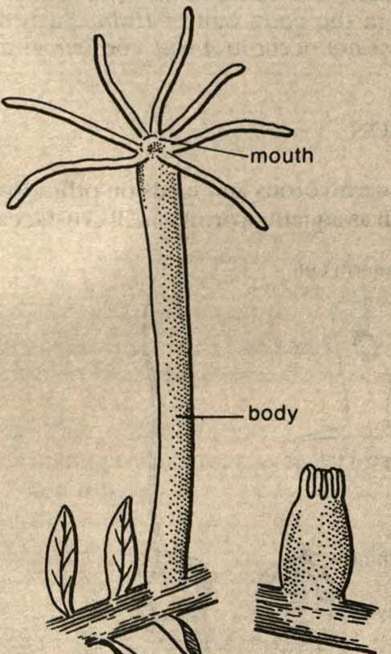


FIG. 7.1 A: *Hydra* when expanded and B: *Hydra* when contracted

Hydra is found in cool, clean, fresh-water ponds, lakes, and streams. It usually attaches itself to submerged stones and weeds.

STRUCTURE

Hydra is a slender, flexible, multicellular animal (metazoan) with a hollow, cylindrical body about 10 mm in length [Fig. 7.1]. At one end the body is closed with a flat, sticky foot called the **basal disc** and at the opposite end there is a conical projection called the **hypostome**, with a small **mouth** at its centre [Fig. 7.2]. *Hydra* uses its basal disc to attach itself to various objects and to move itself. From around the base of the hypostome rise six to ten thread-like hollow **tentacles**. The ends of the tentacles and body are provided with cells called **cnidoblasts**, which enable *Hydra* to 'sting' its prey. The mouth opens into a large cavity in the body called the **coelenteron**. This cavity extends into the tentacles also and is enclosed by a **body wall**. This body wall is made up of two layers of cells; the outer layer being called the **ectoderm** and the inner layer the **endoderm**. These two layers are separated by a non-cellular, elastic, supporting sheet of protoplasm called the **mesogloea**.

The **ectoderm** is made up of a number of specialised cells. These are only briefly described here:

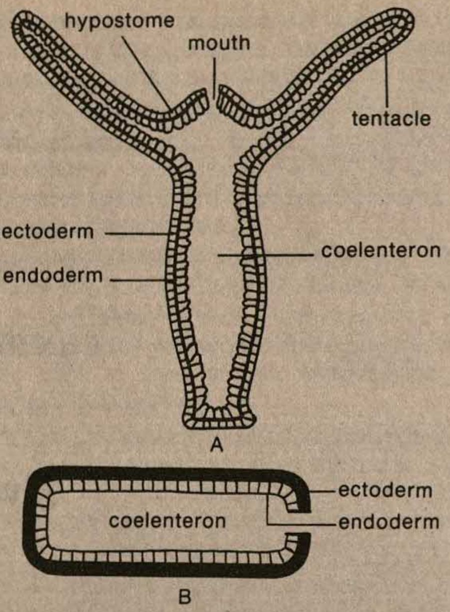


FIG. 7.2 A: Longitudinal section through *Hydra* and B: Transverse section through *Hydra*

Epithelio-muscular cells are the living outer cells which lie parallel to the axis of the body of *Hydra*. They contract and shorten the body for movement and locomotion.

Interstitial cells are found between epithelio-muscular cells. They are reserve cells which are used to replace any worn-out specialised cells.

Cnidoblasts are also placed between muscle cells. They are pear-shaped [Fig. 7.3] and contain a paralysing or poisonous fluid in a sac called the **nematocyst**. A needle-like 'trigger hair', called a **cnidocil**, projects outward from the mouth of the sac. If any object touches the cnidocil, the paralysing fluid is automatically ejected by the hair and the prey is stung.

Nerve cells form a network around the body of *Hydra*.

Sensory cells enable *Hydra* to detect and respond to external stimuli.

The **endoderm** of *Hydra* is comprised of other types of specialised cells. These also are only briefly described here:

Nutritive-muscular cells line the **coelenteron** and help in contracting or elongating the body. They also help in the process of feeding. Some of these cells have pseudopodia (like *Amoeba*) with which they encircle and take in the food particles entering the coelenteron. Others possess whip-like projections called **flagella**, with which they cut food material into very small particles. The nutritive-muscular cells digest food **intracellularly.**

Gland cells secrete digestive enzymes into the coelenteron in order to aid **extracellular** digestion of food in **hydra.**

The endoderm also contains **interstitial cells, nerve cells,** and **sensory cells,** which perform the same functions here as in the ectoderm.

The foregoing discussion shows that there is cell specialisation, and hence division of labour among the cells, in the body wall of *Hydra*. Such differentiation does not occur in *Amoeba* or *Spirogyra*.

NUTRITION

Hydra is carnivorous and feeds on other living animals. such as aquatic worms, small crustaceans, and

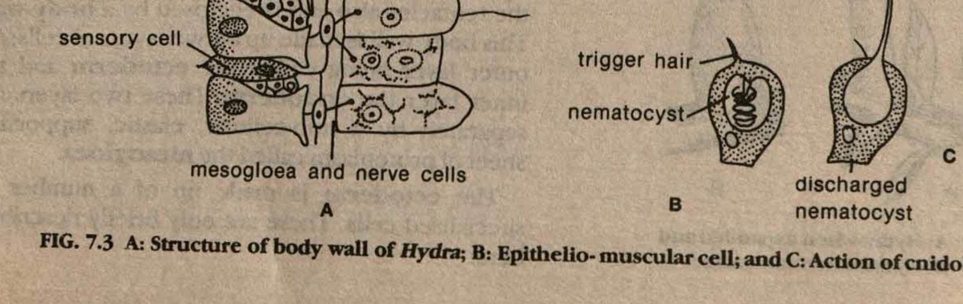


FIG. 7.3 A: Structure of body wall of *Hydra*; B: Epithelio- muscular cell; and C: Action of cnidoblast

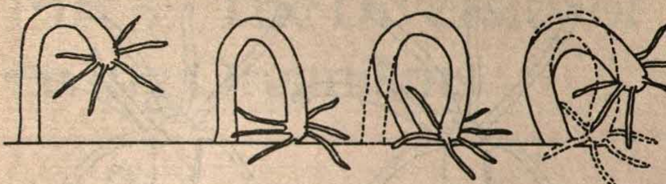


FIG. 7.4 Locomotion of *Hydra* by looping

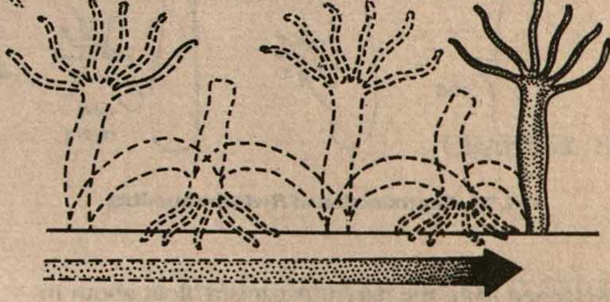


FIG. 7.5 Locomotion of *Hydra* by somersaulting

insect larvae. When a prey comes in contact with the tentacles of *Hydra*, it is injected with the paralysing fluid by the trigger hair of the cnidoblast cells. The tentacles then move to bring the prey within the reach of the mouth. It is taken in and enters the **coelenteron** where gland cells secrete digestive enzymes from the body walls. The food material is broken down into simple substances which are absorbed by the cells by diffusion. This is known as **extracellular digestion.** Some particles from the prey are enclosed by the pseudopodia of the nutritive-muscular cells of the body wall and digested by an **intracellular process**. Undigested food is thrown out through the mouth.

MOVEMENT

Usually, *Hydra* attaches itself to some object (like a stone or weeds) under water. It moves in response to external stimuli, in pursuit of prey, and in order to change its location when necessary. It employs several modes of movement, which are as now discussed.

Looping: This motion occurs as follows: Initially, *Hydra* is resting vertically on its basal disc (foot) [Fig. 7.4]. Then it bends over till the tentacles grip the supporting surface at some distance from the foot. Now, the foot is lifted off the surface and brought nearer the tentacles. Finally, the tentacles lift off the surface and the body becomes upright again. Such steps are repeated to cover the required distance.

Somersaulting: In this case, when the body has been looped and the tentacles have gripped the support, the foot is released completely and goes over to the other side of the tentacles. The basal disc then takes a new grip on the surface, the tentacles are released, and *Hydra* becomes vertical again. Such somersaults are repeated to cover the required distance. This is the fastest means of locomotion of *Hydra* [Fig. 7.5].

Gliding: The basal disc can send out pseudopodia-like extensions, with the help of which, *Hydra* can skim or glide along a surface.

Walking: *Hydra* can turn itself upside down and walk on its tentacles.

RESPIRATION AND EXCRETION

The cells of the ectoderm are directly in contact with the water around *Hydra*. They absorb the water and use the oxygen dissolved in it for respiration. Similarly, the endoderm also depends on diffusion for respiration. The undesirable carbon dioxide and water, and the waste products of metabolism, are allowed to diffuse out of the body into the surrounding water.

REPRODUCTION

Hydra can reproduce either **asexually** or **sexually**. These processes are described as follows.

ASEXUAL REPRODUCTION (BUDDING)

Adult *Hydra* may bear one or more **lateral buds** on its cylindrical body [Fig. 7.5]. These are swellings on the surface which elongate and develop the organs of *Hydra*. Each bud develops a hypostome, a mouth, and a few tentacles. The buds then get

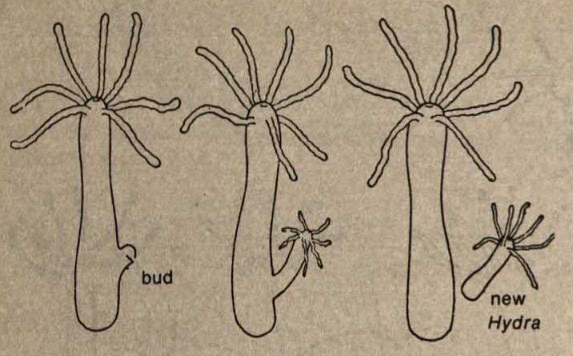


FIG. 7.6 **Reproduction of *Hydra* by budding**

detached from the parent organism, float about in the water for about two days, and then fix themselves onto an underwater object. There they feed and grow into adult animals. Budding is the commonest form of reproduction of *Hydra*.

SEXUAL REPRODUCTION

Hydra reproduces sexually, especially when the temperature of its environment is low. It is **hermaphrodite** in nature. This means that it possesses both male and female characteristics in the same body. Several **testes** (which produce **spermatozoa** or sperms) are situated just below the tentacles [Fig. 7.7]. A single **ovary** (which produces an **ovum**) is situated nearer the foot of the body. Sperms mature earlier than the ovum, and are discharged into the surrounding water by the testes. They swim and reach the ovary, where one sperm fuses with the ovum to form a **zygote**. The zygote remains attached to the parent *Hydra* and develops into an **embryo**. A protective **cyst** is secreted around the embryo to keep it dormant. At this stage, the embryo may be detached from the parent organism. After a period of rest, the cyst wall is ruptured and a *Hydra* hatches out. It possesses a hypostome, a mouth, and several tentacles, and floats about independently in the water. After a few days, it attaches itself to some convenient object and begins to feed and grow.

EXERCISES

1. Draw a simple diagram to illustrate the structure of *Hydra* and label the following parts: (i) mouth; (ii) hypostome; (iii) tentacles; (iv) coelenteron; and (v) basal disc.

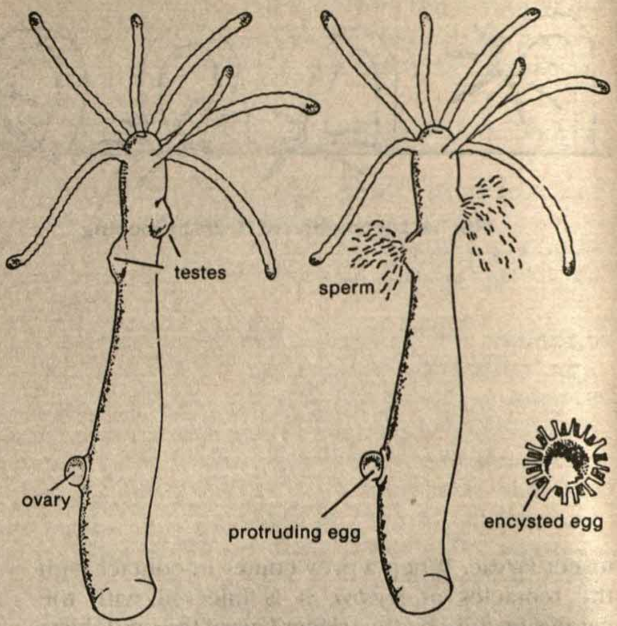


FIG. 7.7 Sexual reproduction in *Hydra*

2. Name the three layers of specialised cells found in the body wall of *Hydra*.
3. (a) What are the functions of the epithelio-muscular cells in the ectoderm?
   (b) With the aid of simple diagrams, describe the structure and action of a cnidoblast cell.
4. (a) Where do the nutritive-muscular cells lie in the endoderm?
   (b) What are their functions?
5. (a) Describe the processes of ingestion and digestion of food with respect to *Hydra*.
   (b) What is the difference between extracellular and intracellular digestion?
6. (a) In how many ways can locomotion of *Hydra* occur? Name them.
   (b) Which is the fastest mode of locomotion?
7. How do the ectoderm and endoderm cells respire and excrete in *Hydra*?
8. Name, and briefly describe, the modes of reproduction in *Hydra*.
9. Bring out five similarities and five differences between: (a) *Amoeba* and *Hydra* and (b) *Spirogyra* and *Hydra*.
10. Do you agree that *Hydra* is a more complex and specialised organism than either *Amoeba* or *Spirogyra*? Give reasons for your answer.
11. What do you understand by 'physiological division of labour'? Explain with reference to *Hydra*. Extend your answer to explain the above term with reference to (i) the tomato and (ii) the human body.

Part 3: The Diversity of Living Organisms

CHAPTER 8

The Nomenclature and Classification of Living Things

Our planet is populated by hundreds of thousands of living organisms. Many common life forms (like the horse, the buffalo, and the penicillin mould) are very useful to us. Other rare organisms (like the duck-billed platypus, the kiwi, and the koala bear) are chiefly of scientific interest. Information about living things has to be organised in order to make it useful to us, and also in order to make our knowledge more precise. As we saw in Part 1, it is best to group organisms according to their natural similarities and relationships. The branch of biology which deals with the naming and classification of living organisms is known as **taxonomy** or **systematics**.

Each animal or plant has different names in various languages and countries. For a scientific understanding, we must use the *same name* for a particular organism all over the world. Such a universal method of naming animals and plants was introduced by a Swedish biologist named Carolus Linnaeus (1707–78). This method is called the **binomial system of nomenclature.** Such a system of classification is now used all over the world and it enables any biologist working in any part of the world to know exactly which living organism another biologist belonging to some other part of the world is referring to. This system depends on the classification of living things. As we saw earlier, all things in our world can be placed either in the group of living things or in the group of non-living things. The former group can further be divided into the group of all plants and the group of all animals. Thus, all things can be grouped into the **mineral kingdom**, the **plant kingdom**, and the **animal kingdom**. The last two kingdoms can be subdivided into such smaller groups as phylum, class, order, family, genus, species, and subspecies. In the binomial system of nomenclature, an animal or plant is identified by the genus and the species to which it belongs. Thus, the name of an organism (given in *italics*) consists of two parts: the **generic name** or **genus** (always beginning with a capital letter) and the **specific name** or **species** (always beginning with a small letter). A genus is a group of species having certain common features, while a species is a group of living organisms which differ from all other organisms in one or more ways. The language used by Linnaeus was Latin, and all biologists have followed the same. Hence, the biological name of man is *Homo sapiens*, where *Homo* is the generic name or genus and *sapiens* is the specific name or species.

The binomial nomenclature of some of the common animals and plants is given in Table 8.1.

The basic unit of natural classification is the **species**. It is the smallest group into which individual living organisms can be placed on the basis of natural similarities among them. As just stated, a **species** is a group of similar individuals who differ from all other organisms in one or more ways.

Table 8.1 Binomial Nomenclature of Some Common Animals and Plants

COMMON NAME	GENERIC NAME OR GENUS	SPECIFIC NAME OR SPECIES
Mouse	*Mus*	*musculus*
Indian elephant	*Elephas*	*indica*
Pigeon	*Columba*	*livia*
Common Indian frog	*Rana*	*tigrina*
Cobra	*Naja*	*tripudians*
House-fly	*Musca*	*domestica*
Banana	*Musa*	*paradisiaca*
Rice	*Oryza*	*sativa*
Chilli	*Capsicum*	*frutescens*
Pea (edible)	*Pisum*	*sativum*
Mustard	*Brassica*	*campestris*
Sunflower	*Helianthus*	*annus*

Members of one species can breed among themselves to give rise to fertile offspring which bear all the group characteristics of the species and resemble their parents. The members of one species cannot breed with the members of a different species. Orange, watermelon, banana, grapefruit, and brinjal are five species of **plants** and cow, lion, horse, peacock, and frog are five species of **animals**.

Several species are often related to each other by some common characteristics. In such a case, they are grouped into a larger unit called a **genus**. For example, potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), and brinjal (*Solanum melongena*) are three species which belong to the genus *Solanum*. Similarly, tiger (*Felis tigris*), lion (*Felis leo*), leopard (*Felis pardus*), and the household cat (*Felis domestica*), all belong to the genus *Felis*.

In the same way, by extension, many related genera (plural of genus) are placed in a larger unit called a **family**. In turn, families form an **order**; orders form a **class**; classes form a **phylum**; and phyla form a **kingdom**. Thus every individual living organism belongs to a species, a genus, a family, an order, a class, a phylum, and a kingdom. Such a classification is illustrated in Table 8.2.

Table 8.2 Classification of Three Familiar Living Organisms

CLASSIFICATION	MAN	COTTON	WHEAT
Species	*sapiens*	*indicum*	*aestivum*
Genus	*Homo*	*Gossypium*	*Triticum*
Family	Hominideae	Malvaceae	Gramineae
Order	Primates	Malvales	Glumiflorae
Class	Mammalia	Angiospermae	Angiospermae
Phylum	Chordata	Spermatophyta	Spermatophyta
Kingdom	Animal	Plant	Plant

EXERCISES

1. Why is it important to have biological names for all living things?
2. Name the three kingdoms into which all things in the world are classified. What is the use of such a classification?
3. Name the smaller groups of similar organisms into which the plant and animal kingdoms are divided, in the order of decreasing size.
4. What do you understand by the words 'species' and 'genus'? Explain, giving five examples of each.
5. (a) What is the binomial system of nomenclature and who introduced it?
   (b) What are the advantages of this nomenclature?
6. All the common plants and animals around you have binomial names in Latin. Consult a knowledgeable person or an encyclopedia, or textbooks of botany and zoology, and write down the generic and specific names of at least ten plants and ten animals not mentioned in this chapter.

CHAPTER 9

The World of Plants

SECTION 1: THE MAJOR GROUPS OF PLANTS

There are two main divisions of the plant kingdom:

(i) **Cryptogams**, which comprise all the 'lower' plants that do not bear flowers or seeds.

(ii) **Phanerogams** (also called **Spermatophyta**), which comprise all the 'higher' plants that bear flowers and seeds.

Both these divisions contain smaller groups of plants which are now briefly described.

CRYPTOGAMS

The plants classified under Cryptogams may be placed in three groups, namely, **Thallophyta**, **Bryophyta**, and **Pteridophyta**. We now describe each of these groups, individually.

THALLOPHYTA

These are the simplest plants. Their bodies consist of either a single cell or a group of cells and are not differentiated into roots, stems, or leaves. Such a plant body is called a **thallus**. The Thallophyta are further divided into three groups:

(i) Algae: These are minute green plants commonly found in water, on damp soil, and on wet walls and roads. Some algae contain other pigments besides chlorophyll. Other algae such as *Euglena* and *Chlamydomonas* are unicellular, whereas still others such as *Spirogyra* [see Fig. 6.2] and *Ulothrix* are multicellular (see Fig. 9.1). All of them manufacture their own food.

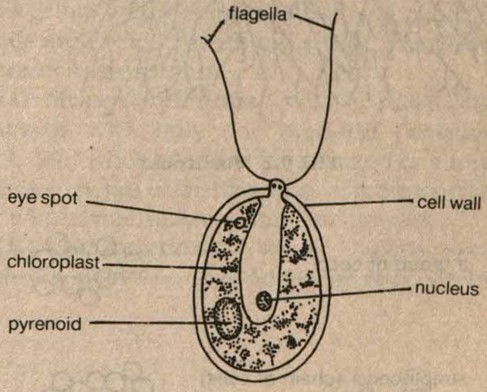


FIG. 9.1 Algae

(ii) Fungi: These are non-green plants which cannot manufacture their own food. Some fungi such as mushrooms [Fig. 9.2], moulds, toadstools, and yeast, which feed on dead or decaying organic matter, are called **saprophytes.** Others, such as rust fungus (found on wheat plants), bracket fungus (found on living tree trunks) [Fig. 9.3], and dandruff, which feed on living organisms, are called **parasites.** Fungi need moist and dark conditions to grow.

(iii) Bacteria: These are non-green, unicellular plants which are visible only under a microscope. Like fungi, they cannot manufacture their own food

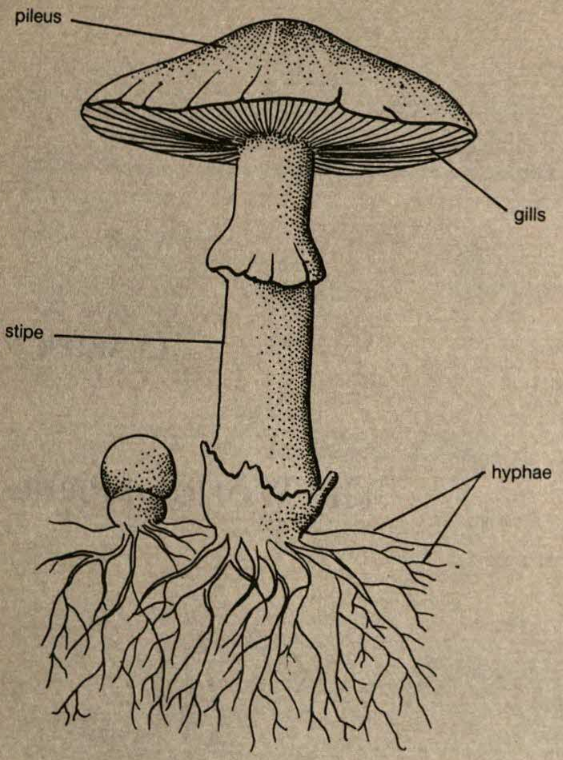


FIG. 9.2 Mushroom

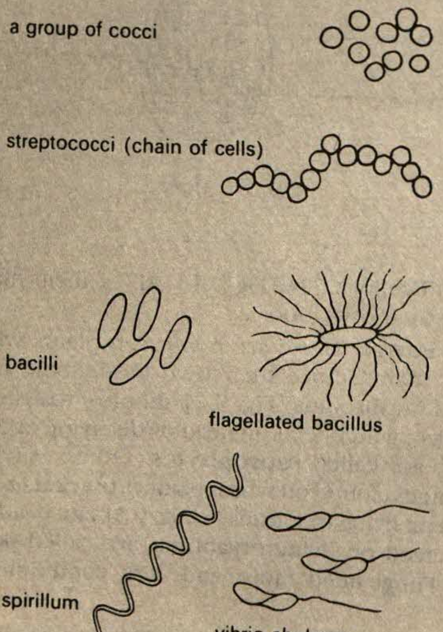


FIG. 9.4 Various types of bacteria

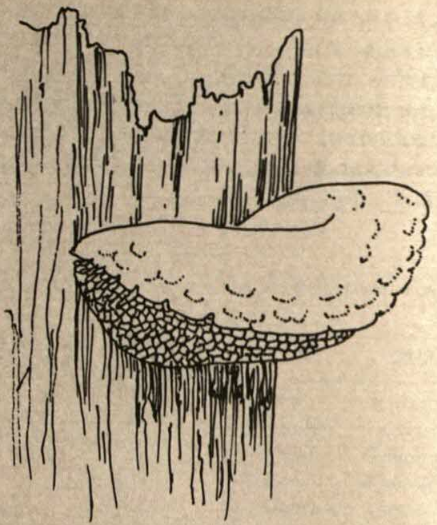


FIG. 9.3 Bracket fungus growing parasitically on a tree trunk

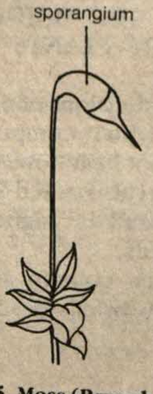


FIG. 9.5 Moss (Bryophyta)

and live in the form of either saprophytes or parasites. They are found everywhere; in the air around us, in fresh water and salt water, and in most living things [Fig. 9.4].

BRYOPHYTA

The flowerless plants classified under Bryophyta are more complex in structure than the Thallophyta. They fall into two groups, namely, mosses and liverworts. They are green, and can manufacture their own food. They grow on damp walls, rocks, and soil, and also on the bark of trees. Some Bryophyta have root-like structures called **rhizoids**, but these are not true roots. Also, some (such as the mosses) have leaf-like structures [Fig. 9.5].

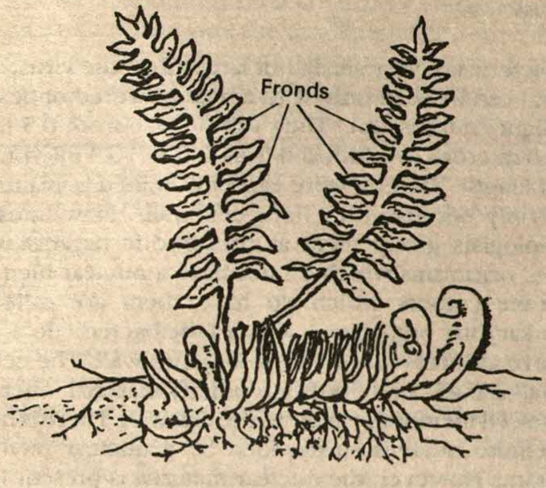


FIG. 9.6 Fern (Pteridophyta)

PTERIDOPHYTA

These are the most complex Cryptogams. In Pteridophyta, the plant body is differentiated into roots, stems and leaves. However, they do not bear any flowers. Pteridophyta mostly grow on land, but some are found in water. The three types of Pteridophyta are ferns [Fig. 9.6], club-mosses and horsetails.

PHANEROGAMS (THE SEED-BEARING PLANTS)

These are flowering plants which bear seeds. Phanerogams (or Spermatophyta) include most of the common trees, shrubs, and herbs. These plants have roots, stems, and leaves, and manufacture their own food. There are two groups of Phanerogams, namely, Gymnosperms and Angiosperms.

GYMNOSPERMS

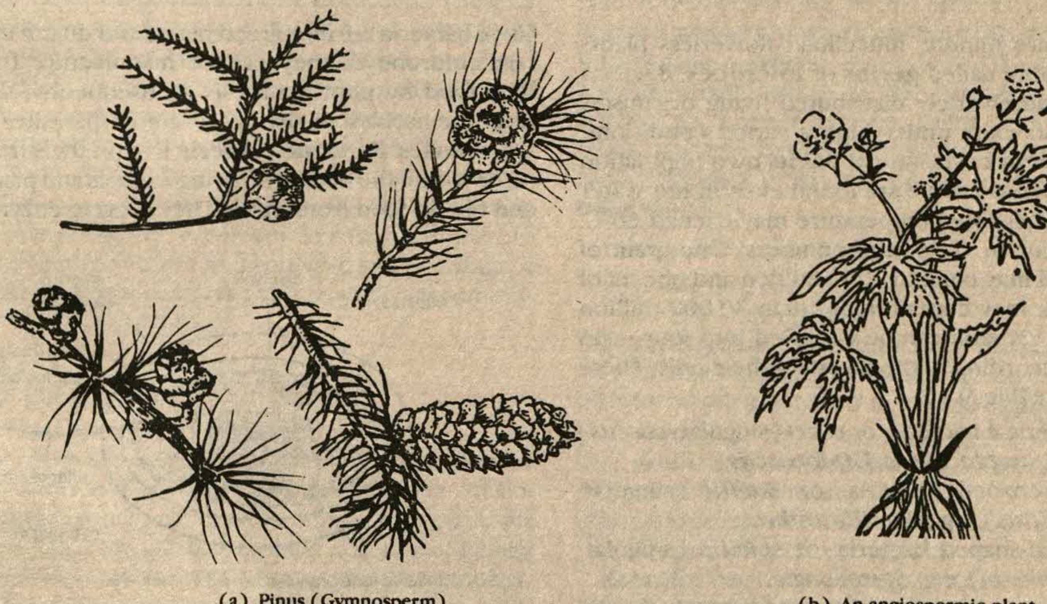
This group consists of those flowering plants whose seeds are not contained within the fruit. Such plants are mostly found in the hills. Examples of Gymnosperms are yew, cypress, fir, larch and pine (*Pinus*) [Fig. 9.7].

ANGIOSPERMS

This group includes most of our land plants. Their seeds are enclosed within the fruit. There are two kinds of Angiosperms:

(i) Monocotyledons, whose seeds contain embryos with only one seed-leaf (**cotyledon**) each, and whose flowers have three (or a multiple of three) petals each. Examples of monocotyledons are wheat, rice, maize, palms, and grasses.

(ii) Dicotyledons, whose seeds contain embryos with two seed-leaves or two cotyledons



(a) Pinus (Gymnosperm)

(b) An angiospermic plant

FIG. 9.7 Phanerogams

each, and whose flowers usually have five (or a multiple of five) petals each. Examples of dicotyledons are gram, pea, sunflower, radish, and mustard.

SECTION 2: NON-FLOWERING PLANTS

BACTERIA

Although bacteria have always been present everywhere in our environment, we were not aware of their existence prior to the nineteenth century. It was only in 1861 that the French scientist Louis Pasteur (1822–95) conclusively proved that minute living organisms are responsible for the decay of our food. For example, milk sours because of the presence of bacteria in it. Pasteur showed that these bacteria can be destroyed by heating, after which milk could be preserved for a longer time. A few years later a German doctor named Robert Koch (1843–1910) used a microscope to observe and identify the bacteria which cause certain human diseases. He also devised a way of growing (culturing) bacteria in a laboratory, i.e., outside a living body. Since this pioneering work, a great deal of research has been done by microbiologists. As a result, we have learnt much about the nature of bacteria and their importance in our lives.

SHAPE AND SIZE OF BACTERIA

Bacteria are minute, unicellular flowerless plants and are often called **germs** or **microbes**. Bacteria are the most widely distributed living organisms which can exist under highly varied conditions. Every type of environment has its own population of bacteria, and some are found even in hot water springs where the temperature may exceed 60°C. They occur in very large numbers. One gram of fertile soil may contain 1000 million and one ml of fresh milk may contain more than 30,000 million bacteria! Bacteria can be classified into four main groups according to the shapes of their cells. These groups are [Fig. 9.4]:

(i) Spherical bacteria, or *cocci* (singular: *coccus*) e.g., *Streptococcus, Diplococcus.*
(ii) Rod-shaped bacteria, or *bacilli* (singular: *bacillus*), e.g., *Bacillis anthrax.*
(iii) Spiral-shaped bacteria, or *spirilla* (singular: *spirillum*), e.g., *Spirochaete.*
(iv) Comma-shaped and S-shaped bacteria, or *vibrios* (singular: *vibrio*), e.g., *Vibrio cholerae.*

STRUCTURE

Bacteria are very small, but larger than the viruses, and can be seen only with a high-powered optical (light) microscope. They vary in size from 0.5 to 5.0 microns in width and from 2.0 to 10.0 microns in length. Bacteria were earlier classified as plants, mainly because they have cell walls. Now, most biologists group them as prokaryotic organisms, i.e., organisms which do not have a nuclear membrane (others which do have them are called eukaryotic organisms). Most of the bacteria do not have chlorophyll or a cellulose cell wall. The cell wall is made up of proteins or fatty material. There is a cell membrane inner to the cell wall. There is no definite nucleus surrounded by a nuclear membrane. However, the nuclear material is present in the cytoplasm. The cytoplasm also contains granules of reserve food such as glycogen, fats, ribosomes, and enzymes. There are no Golgi bodies, mitochondria, endoplasmic reticulum, and large vacuoles.

In some species of bacteria, the cell wall is surrounded by a thin jelly-like sheath or capsule. Some forms of bacteria have one or two delicate, thread-like **flagella** attached to their bodies. Such bacteria are said to be **motile** and can move with the aid of flagella. Bacteria which do not possess flagella are said to be **non-motile**; they cannot move about on their own.

NUTRITION

Since bacteria are non-green plants and do not contain chlorophyll, they cannot manufacture their own food by photosynthesis. Consequently, they feed themselves by living as either parasites or saprophytes. **Parasitic bacteria** live on the surface of, or within the bodies of, living animals and plants, and obtain food from them. They secrete enzymes

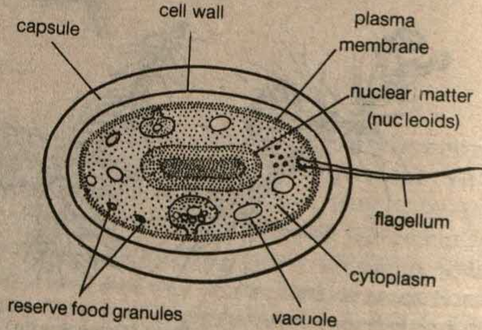


Fig. 9.8 Bacteria

into the surrounding medium, where extra-cellular digestion occurs and the products of digestion diffuse into the cell for its growth, respiration and reproduction. By doing this, parasitic bacteria harm their animal and plant hosts to a great extent. **Saprophytic bacteria** live and feed on the organic matter in the remains of dead animals and plants and thus bring about their decay and decomposition.

RESPIRATION

Some bacteria respire by taking in oxygen, while others do not. **Aerobic bacteria** take in oxygen to oxidise the glucose in their protoplasm. The energy released in this process is used for their activities. **Anaerobic bacteria** do not use oxygen; they directly break down their protoplasmic glucose into simpler substances. Energy is released in this process also, but it is lesser than in aerobic respiration. Nevertheless, it is sufficient for anaerobic bacteria to function, grow, and reproduce. These bacteria which decompose the remains of dead animals and plants are called anaerobic bacteria. It may be noted that some bacteria can live equally well with or without oxygen.

REPRODUCTION

Bacteria reproduce by the process of cell division called **binary fission**. The rate at which cell division occurs depends on the environment. The conditions that are favourable to the quick growth and reproduction of bacteria are warmth, moisture, presence or absence of oxygen, availability of organic food material, etc. Given these conditions, a bacterium grows to its full size within 20 minutes and then divides into two daughter bacteria twice or thrice in one hour. For example, this happens in the case of the hay bacterium. Even at the minimum rate of reproduction in favourable surroundings, a single bacterial cell gives rise to over sixteen million bacteria in 24 hours!

SPORE FORMATION

When bacteria are placed in conditions of excessive cold (below 5°C), excessive heat (above 70°C), drought, etc., binary fission cannot take place. In such a case, some bacteria form a thick and strong wall around themselves and become **endospores**. Within each spore the protoplasm becomes concentrated in one region of the bacterial cell. The bacterium then becomes **dormant** (inactive) and survives through adverse conditions in this manner. These spores are able to resist prolonged unfavourable conditions such as drought, high or low temperature, and strong chemicals. Some can even withstand as much as 16 hours of constant boiling. Spore formation is not a method of reproduction because a bacterium forms one spore and when favourable conditions return, the outer wall breaks and the bacterium becomes active once more. It then begins reproducing by binary fission again.

BACTERIA AND MAN

Bacteria carry out many important activities which affect our lives. Some of these are now described.

Useful bacteria: Bacteria help us by bringing about the decomposition of dead organisms. They break down the complex substances in the bodies of dead animals and plants into simple substances such as water, carbon dioxide, ammonium compounds, and nitrates. These simple products are dispersed in the atmosphere and the soil. From there, they are taken up by plants and are used to manufacture food by photosynthesis. Since plants form the basic food of human beings, bacteria thus help man.

By carrying out the decay of organic matter, bacteria help enrich the soil in substances such as mineral nitrates. By doing this, they increase the fertility of the soil. Bacteria also play an important role in nitrogen-fixing. In this process, certain soil bacteria convert nitrogen gas from the atmosphere into organic nitrogen compounds. Thus, bacteria are important agents in the nitrogen cycle of Nature. As a result of their useful decaying activities, bacteria help scavenge the surface of the earth. Disposal of human sewage depends upon bacterial decay.

Further, bacteria are used for:

(i) producing curd, butter, and cheese from milk and flavouring them;
(ii) retting hemp, flax and jute, in the production of linen, sacking, and other related items;
(iii) fermenting tobacco leaves, to improve their aroma;
(iv) producing vinegar from weak alcohols;
(v) tanning leather; and
(vi) producing valuable vitamins and antibiotic drugs, such as Streptomycin.

Harmful bacteria: Bacteria which bring about decay become extremely harmful when they attack our food, because they produce poisonous substances in it. That is why spoilt food causes food poisoning. Therefore, it is essential to protect our food from such bacteria. This is possible only when we maintain hygienic conditions in our homes.

Some bacteria live as parasites within our bodies. There, they release **toxins**, which are poisonous, and cause diseases such as tuberculosis, cholera, diphtheria, dysentery, and diarrhoea. Bacteria enter our systems through the delicate linings of the nose, throat, lungs, and alimentary canal, and through cuts and wounds. Besides man, they attack animals and plants and cause diseases in them.

Denitrifying bacteria: We can control harmful bacteria in the following ways:

(a) Sterilisation: Sterilisation is the procedure of removing bacteria from an object by killing them using either heat (steam under pressure, in an autoclave) or chemicals (such as penicillin, Streptomycin, sulpha drugs, alcohol, carbolic acid, and phenyl). Surgeons have all their surgical instruments, dressings, and clothes sterilised before going into the operation theatre. This ensures that bacteria do not reach the patient and infect his body during an operation.

(b) Preservation of food: Since bacteria contaminate almost every type of food material, we have had to develop several methods for the preservation of food. The more significant methods are as follows.

(i) Canning, which involves heating the food to high temperatures in order to kill any bacteria present in it, and then sealing it (while still hot) in air-tight, sterilised cans. Bottling of fruits, juices, etc., is a similar process. No bacteria can contaminate the food until the cans and bottles are opened.

(ii) Dehydration, which consists of removing up to 95% of the water content of foods such as vegetables, fruits, and seeds. Bacteria and other microorganisms cannot grow and multiply within the dehydrated material, since they require moisture to flourish.

(iii) Refrigeration, which involves keeping foods at low temperatures. Bacteria become dormant at temperatures below 5°C and hence the spoilage and decay of refrigerated food take place very slowly. However, in this method of preservation, the bacteria are not killed.

(iv) Pasteurisation, which is a method of sterilising milk. Fresh milk is heated to a temperature of 70°C to 72°C for at least 15 seconds, and then suddenly cooled to below 12°C. This kills most of the active bacteria and prevents the milk from souring easily.

(v) Brining, which involves placing the food in a strong solution of salt. The salt solution causes water to be drawn out of the bacterial cells by plasmolysis and the bacteria become dormant due to drought.

(vi) Strong sugar solution, which causes water to be drawn out of bacterial cells. This method is used in making jams and marmalades.

(vii) Pickling in vinegar, which prevents the multiplication of bacteria in food by the action of the acetic acid present in vinegar.

FUNGI

Fungi are a group of non-green plants such as mushrooms, toadstools, moulds, smuts, and rusts. None of them contains chlorophyll and hence they cannot manufacture their own food by photosynthesis. Consequently, fungi depend on other organisms for nutrition. **Parasitic fungi** live in or on other organisms to obtain their food from their tissues, while **saprophytic fungi** live in or on decaying organic matter and dead organisms and depend on them for their nutrition. Some fungi live as **symbionts** in association with some algae (lichens) and roots of forest trees (mycorrhiza).

Fungi are found in all kinds of habitats where conditions, such as availability of sufficient food, warmth, and moisture, are favourable for their growth. They can grow well both in light and darkness. Their body is called the **mycelium** and consists of a large number of branched threads called **hyphae**. Fungi reproduce by forming numerous minute unicellular spores which are easily blown about by the wind. Some fungi reproduce sexually also.

MOULDS

When bread, overripe fruits, cooked food, or leather are left uncovered for some time in a damp and warm place, these materials get covered with **moulds**. These moulds may be the grayish *Rhizopus* and *Mucor*, or the blue-green *Penicillium*, or the yellow-green *Aspergillus*.

Mucor: This is commonly known as pin mould and spreads like a cobweb on animal dung, wet shoes, moist bread, rotten fruits, decaying vegetables, etc., kept in damp and warm conditions.

Structure: The plant body of *Mucor* is called **mycelium**, and it consists of a network of branched threads, each of which is called **hypha** [Fig. 9.9]. We can observe this structure when a sample of *Mucor* is examined under a microscope.

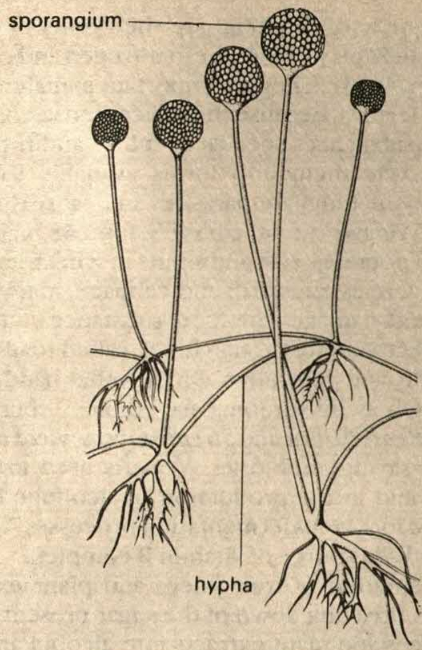


FIG. 9.9 Mycelium of *Mucor*

The hyphae are tube-like structures bounded by walls of fungus. Within them is a granular cytoplasm which contains many small nuclei and vacuoles. The hyphae are not divided into distinct cells by cell walls across the tube-like structure. Some of the hyphae are slightly arched; such hyphae are called **stolons.** The stolons spread parallel to the surface of the substratum material on which the mycelium has embedded itself. These stolons bear some branches which are not parallel to the base, but remain upright in the air. These erect, aerial structures are themselves unbranched and are called **sporangiophores.** They appear only at intervals along the stolons. The sporangiophores have small black swollen spore sacs, called **sporangia**, at their tips. The stolons also bear clusters of branched hyphae called **rhizoids** which spread downwards and penetrate the substratum. These hyphae fix the mycelium into the substratum and also absorb food from it.

Activity 1: Observation of hyphae and sporangia

Moisten a slice of bread and place it in a dish under a bell-jar, or in a can with a tightly fitting lid. Leave the container in a warm place. After a period of 24 hours or more, you will find the bread covered with mould (either *Mucor*, or *Pencillium*, or both). Examine the mycelia under a microscope. You will observe hyphae and sporangia in various stages of growth.

Nutrition: *Mucor* does not possess chlorophyll and so cannot manufacture its own food. It is saprophytic in nature and thus lives on decaying organic matter or dead organisms. Its rhizoids penetrate into the substratum and secrete digestive enzymes into it. These enzymes break down the complex and insolube substances in the substratum into simple and soluble substances, which are absorbed by the rhizoids for the survival and growth of the mycelium.

Respiration: *Mucor* respires aerobically, i.e., it uses oxygen from the air to obtain energy for its activities. However, some of the hyphae which have penetrated deep into the substratum respire anaerobically, i.e., without using oxygen.

Reproduction: *Mucor* usually reproduces asexually, but, sometimes, it may reproduce sexually also.

Asexual reproduction takes place with the help of spores produced in sporangia formed at the tips of sporangiophores. The sporangia are black, spherical spore sacs. Within a sporangium is present a dense cytoplasm containing many small nuclei. This cytoplasm breaks up into a large number of minute bodies called **spores.** Each spore is a thick-walled body containing some cytoplasm and many nuclei. The spores are contained in an outer region of a sporangium which is walled off from the dome-shaped central region. This central region of the spore sac is called the **columella** and does not contain spores. Due to accumulation of a fluid in the columella, it swells up and exerts pressure on the thin and brittle wall of the sporangium, which bursts and the spores are set free. The spores are so light that they are blown about until they reach a suitable place where moisture, food, and warmth become available. Given these favourable conditions, the spores germinate and set up the new mycelia on a new substratum and the life cycle begins all over again.

Sexual reproduction takes place by means of **conjugation.** This happens when conditions do not favour spore formation, specially when food is not easily available. When two hyphae borne on the mycelia of different strains developed from two different spores come close together, conjugation tubes grow out from each. The conjugation tubes come in contact with each other at their tips. As they elongate, they push the parent hyphae away from each other. Each tube is divided by a partition wall into a **basal suspensor** and a **terminal**

gametangium. The contents of each gametangium give rise to a gamete, each containing many nuclei. The two gametes are identical in all respects. The end walls of the two gametangia get dissolved and the two gametes fuse together to form a zygospore. The zygospore swells up and develops a thick black protective wall around it. It undergoes a period of rest and finally its outer wall bursts and the inner wall grows out to form a tube called the sporangiophore with a spherical sporangium at its tip. This sporangium contains a large number of spores but no columella. When the wall of the sporangium bursts, the spores are liberated. These are blown about in the wind and finally settle on a suitable substratum to germinate and grow into new mycelia of *Mucor.*

The Importance of Fungi

While most of the fungi are harmful to man, some are beneficial and even indispensable.

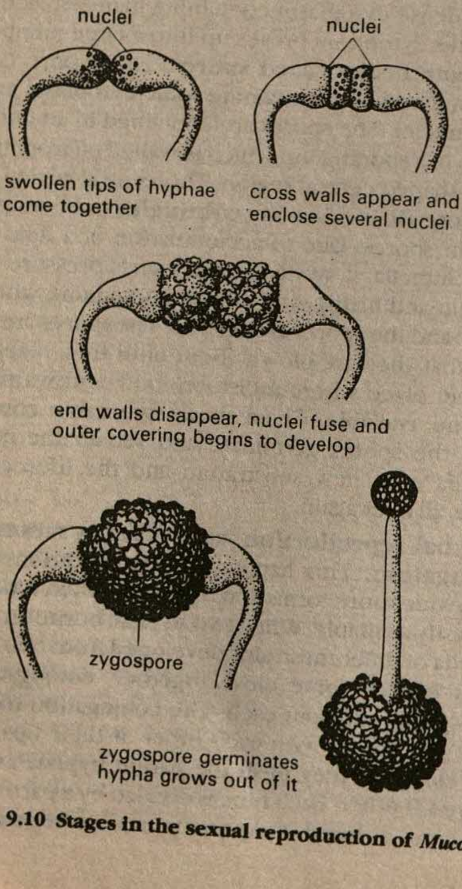

nuclei
nuclei
swollen tips of hyphae come together
cross walls appear and enclose several nuclei
end walls disappear, nuclei fuse and outer covering begins to develop
zygospore
zygospore germinates hypha grows out of it

Fig. 9.10 Stages in the sexual reproduction of *Mucor*.

A majority of the fungi are the agents of decay and, as such, play a vital role in nitrogen and carbon cycles in Nature. They are important in maintaining the soil fertility because they decompose complex organic substances such as cellulose and proteins, and convert them into forms available to crop plants. Many fungi are parasites and cause diseases such as ringworm or athlete's foot in man; late blight in potatoes; rust and smuts in wheat; and mildew in cereals, mustard, and cabbage. Many fungi decay, and damage our food substances, clothes, books, leather, etc. Certain fungi, called toadstools, are deadly and poisonous. On the other hand, some fungi such as mushrooms are edible. Other fungi such as *Penicillium* and *Streptomyces*, yield important life-saving antibiotics. Yeast is used in bread making and in the production of alcoholic beverages, and in various fermentation processes. Yeast is also used as a source of vitamin B complex.

Fermentation of fruit juices and plant extracts involves breaking down of the sugar present in the fruit juices and plant extracts into alcohol and carbon dioxide by means of enzymes produced by yeast cells. The alcohol thus produced is used in the manufacture of alcoholic beverages. The alcohol is also converted to acetic acid, from which vinegar is made. In the process of bread making, a little sugar mixed with yeast is added to dough made from flour. The dough is then left in a warm place for several hours. The action of yeast on the sugar causes carbon dioxide to be given off. This carbon dioxide pushes itself out of the dough and thus leaves it spongy. From this 'risen' dough, bread in the form of loaves is made.

SECTION 3: FLOWERING PLANTS

A STUDY OF SIMPLE HERBACEOUS PLANTS

A typical flowering plant has two main parts: the root system and the shoot system. The root system is embedded in the soil and consists of a main root and branch roots. On the other hand, the shoot system consists of all the organs of the plant which lie outside the soil, and includes the stem, branches, leaves and flowers.

The Root System

The **root system** consists of a **main root** which grows directly downwards into the soil, and which bears numerous branches called **lateral roots** that spread in different directions. Each branch of the,

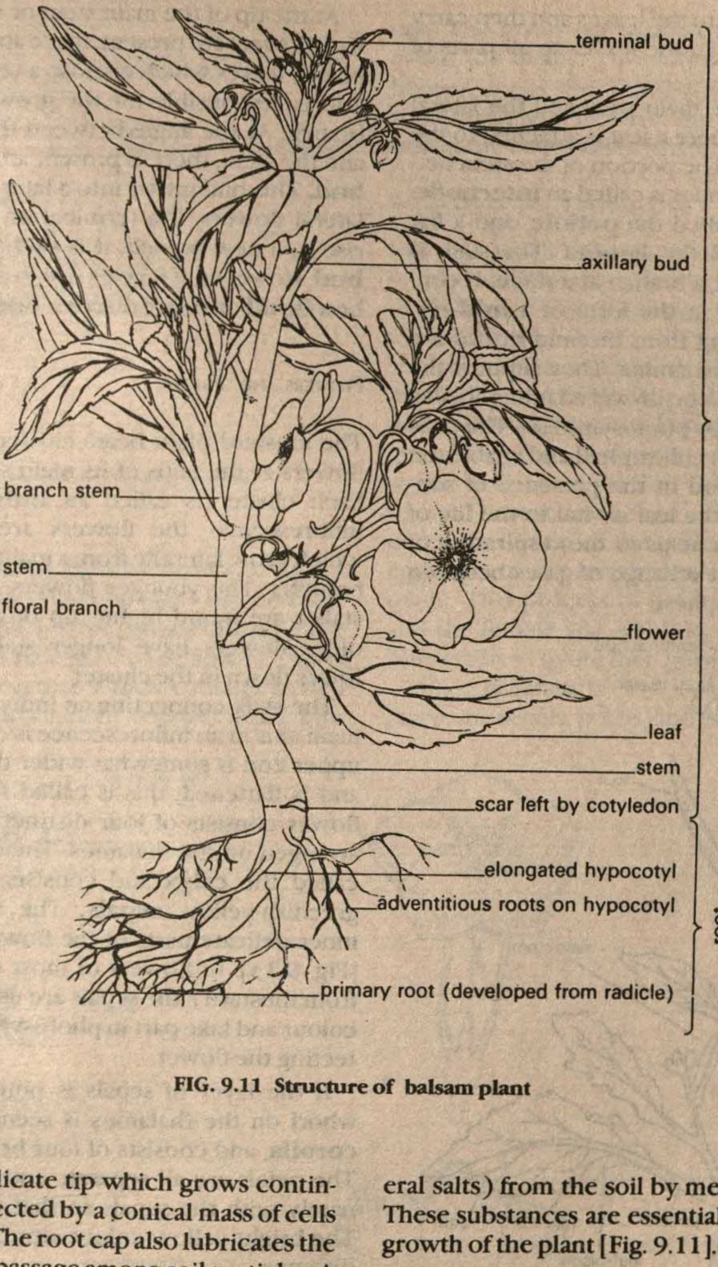


FIG. 9.11 Structure of balsam plant

root system has a delicate tip which grows continually. This tip is protected by a conical mass of cells called the **root cap.** The root cap also lubricates the tip and thus eases its passage among soil particles. A little above the root cap is present a cluster of very fine **root hairs** on each branch. These root hairs can be seen very clearly when some mustard seeds are placed on wet cotton wool and allowed to germinate. It should be noted that on older parts of the root system, these hairs appear withered.

The root system performs two very important functions. First, it fixes the plant firmly in the soil with the aid of the main and lateral roots. Secondly, it absorbs water and dissolved food material (mineral salts) from the soil by means of the root hairs. These substances are essential for the survival and growth of the plant [Fig. 9.11].

The Shoot System

The **shoot system** constitutes the aerial part of the plant. It consists of the **main stem**, which is erect and cylindrical, and the **lateral branches**, which spread sideways from the stem. The stem and the branches perform two chief functions. First, they support the leaves and flowers of the plant and, secondly, they conduct the water and dissolved mineral salts from the roots to the leaves and then carry the food manufactured in the leaves to all parts of the plant [Fig. 9.11].

Leaves arise from the main stem and the lateral branches. The place where a leaf is attached to the stem is called a **node**. The portion of the stem between two successive nodes is called an **internode**. The leaf has a stalk, called the **petiole**, and a flat, green leaf-blade called the **lamina**. The stalk is attached to the stem or a branch at a node. It continues into the lamina in the form of a **mid-rib**. Numerous **veins** arising from the mid-rib form a network throughout the lamina. They support the leaf and also conduct water, dissolved mineral salts, and the food prepared by photosynthesis. The cells of the leaf-blade contain chlorophyll and enable the leaf to manufacture food in the presence of sunlight. This function of the leaf is vital to the life of the plant. The leaf also helps in the respiration of the plant, enabling an exchange of gases between the plant and the atmosphere.

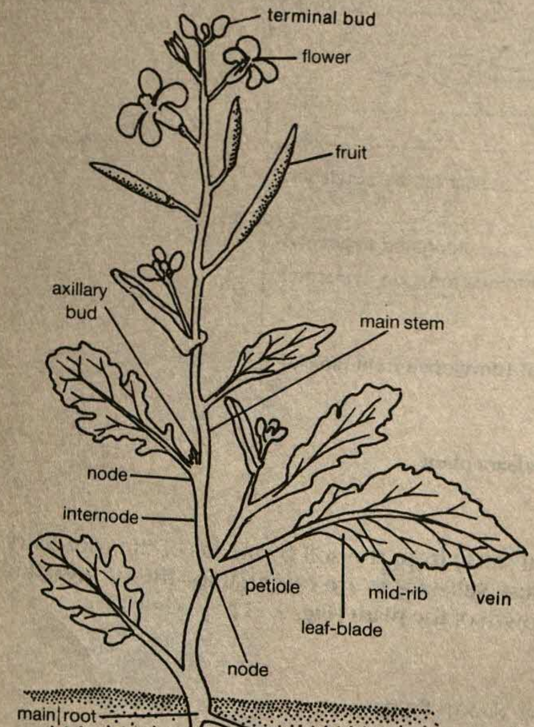


FIG. 9.12 Structure of mustard plant

At the tip of the main stem or of a lateral branch, if no flowers are present, there appear small, closely placed leaves which enclose a **terminal bud.** This bud is responsible for the growth of the stem or branch. At the angle between the petiole of a leaf and the stem, there is present an **axillary (lateral) bud.** This bud grows into a lateral branch or yields lateral flowers. If a terminal or axillary bud gives rise to a new branch, it is said to be a **vegetative bud**. However, if it gives rise to a flower, it is said to be a **floral** or **reproductive bud** [Fig. 9.12].

Flowers and Fruits

The mustard plant bears clusters of bright yellow flowers at the ends of its main stem and branches. Each cluster is called an **inflorescence.** In an inflorescence, the flowers are found on stalks which grow laterally from a main axis (the stem or a branch). The younger flowers, which have short stalks, are found higher up on the main axis; the older flowers have longer stalks and are found lower down in the cluster.

The stalk connecting an individual flower to the main axis in an inflorescence is called a **pedicel**. Its upper end is somewhat wider than the lower end, and is flattened; this is called the **thalamus**. The flower consists of four distinct **whorls** or circles arranged on the thalamus. The outermost whorl is called the **calyx** and consists or four very pale greenish-yellow **sepals.** The sepals protect the inner delicate parts of the flower at the bud stage [Fig. 9.13]. In flowers of most other plants (apart from mustard), the sepals are usually deep green in colour and take part in photosynthesis, besides protecting the flower.

If the layer of sepals is pulled off, the second whorl on the thalamus is seen. This is called the **corolla**, and consists of four bright yellow **petals.** The petals are all separate and are arranged alternately with the sepals so that they form a 'cross'. The bright yellow colour attracts insects even at a distance.

Within the corolla lies the third whorl, called the **androecium**. It consists of six **stamens** and is the male part of the flower. Each stamen is made up of a thin green stalk or filament which carries a yellow, two-lobed head called the **anther**. Numerous minute yellow particles called **pollen grains** are formed inside each anther. Of the six stamens, the two outermost ones contain short filaments; the inner four having longer filaments. Near the base of the stamens are four tiny swellings which are glands

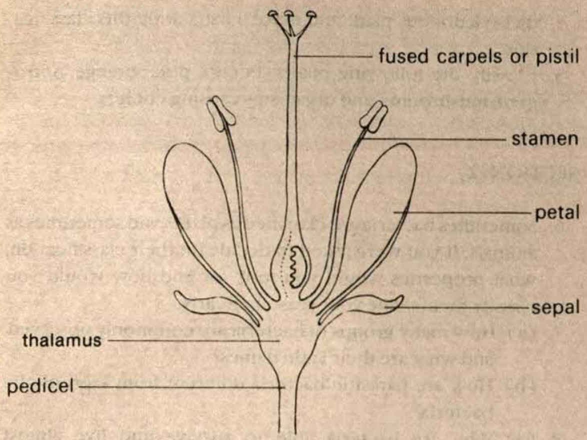


FIG. 9.13 Structure of a typical flower

called **nectaries**. These glands secrete a sugary solution called **nectar** on which many insects feed.

The innermost whorl is the **gynoecium** or the **pistil**, which is the female part of the flower. This is a single tube-like structure which consists of two **carpels** (female reproductive organs) fused into one. The lower part is elongated and wide, and is called the **ovary**. This contains the **ovules** which become seeds after fertilisation. The upper part is a short **style** which carries the **stigma** for the reception of the male pollen grain.

POLLINATION AND FERTILISATION

Insects transfer the pollen grains from the anther of one mustard flower to the stigma of the same flower or to that of another mustard flower. This is known as **pollination.** Each pollen grain contains a male sex cell, whereas each ovule in the ovary of the pistil contains a female sex cell or egg. After a pollen grain has been deposited on the stigma of a pistil, it grows to form a pollen tube which penetrates the stigma and bores down through the style to the ovary. There it reaches an ovule, and the male sex cell from the tip of the pollen tube fuses with the egg cell or the female sex cell contained in the ovule. This process of fusion of the male sex cell and the female sex cell is known as **fertilisation**. The fertilised ovule then grows into a seed.

After pollination and fertilisation have taken place, the sepals, petals, and stamens dry up and fall

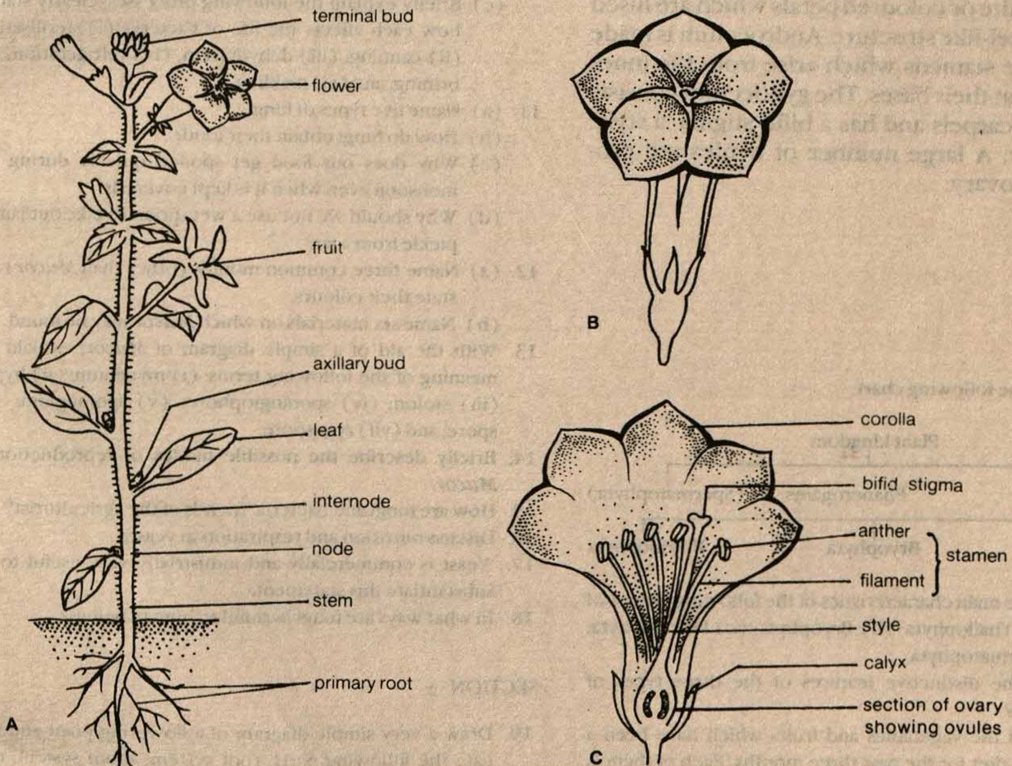


FIG. 9.14 A: Petunia plant; B: Flower; and C: Corolla with stamens (opened out)

off the thalamus, leaving behind the gynoecium. Then, the stigma and the style also dry up and the ovary begins to grow larger. It eventually becomes a fruit even if fertilisation has failed, but the ovules become seeds only if fertilisation has succeeded. Thus, seedless fruits such as bananas are produced without fertilisation having taken place; in grapes, oranges, and lemons, the presence or absence of seeds depends on this same factor.

The seeds within a fruit dry up after the fruit has been used up or has undergone decay. Then they can be sown and new mustard plants can be obtained from them. These new plants undergo the same life cycle in their turn.

PETUNIA PLANT

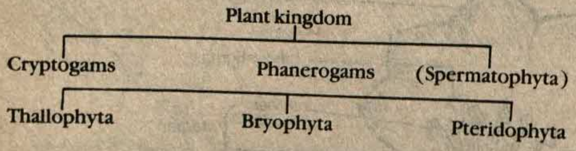
Petunia is an annual garden herb [Fig. 9.14]. The plant has a typical taproot system. The stem bears prominent nodes and internodes. The leaves are small with short stalks (petioles) and develop from nodes. Each leaf has a bud in its axil.

Flowers are large, brightly coloured, funnel-shaped, and bisexual. The calyx consists of five green sepals which are slightly joined. The corolla consists of white or coloured petals which are fused to form a funnel-like structure. Androecium is made up of five free stamens which arise from the inner side of petals at their bases. The gynoecium consists of two fused carpels and has a bifid stigma, a style, and an ovary. A large number of ovules are produced in the ovary.

EXERCISES

SECTION 1

1. Complete the following chart:



2. What are the main characteristics of the following groups of plants? (a) Thallophyta; (b) Bryophyta; (c) Pteridophyta; and (d) Spermatophyta.
3. What are the distinctive features of the three types of Thallophyta?
4. Consider all the vegetables and fruits which have been a part of your diet for the past three months. Each of them is obtained from a plant in the Angiosperm group. Determine whether each is obtained from a monocotyledonous or a dicotyledonous plant and make a list stating this classification.
5. Classify the following plants: Potato, pine, orange, *Spirogyra*, mushrooms, and organisms causing cholera.

SECTION 2

6. Sometimes bacteria are classified as plants and sometimes as animals. If you were asked to decide on their classification, what properties would you look for and how would you classify them? State your reasons clearly.
7. (a) How many groups of bacteria are commonly observed, and what are their Latin names?
   (b) How are parasitic bacteria different from saprophytic bacteria?
8. (a) Why are bacteria able to survive and live almost everywhere?
   (b) What is the difference between aerobic and anaerobic respiration in bacteria? Which mode of respiration releases less energy?
9. (a) How do bacteria reproduce under favourable conditions?
   (b) What happens to bacteria under unfavourable conditions?
10. (a) Specify ten ways in which bacteria are useful to human beings.
    (b) In what ways are bacteria harmful to human beings?
    (c) Briefly explain the following processes, clearly stating how each affects the life of bacteria: (i) sterilisation; (ii) canning; (iii) dehydration; (iv) refrigeration; (v) brining; and (vi) pickling.
11. (a) Name five types of fungi.
    (b) How do fungi obtain their food?
    (c) Why does our food get spoiled quickly during the monsoon even when it is kept covered?
    (d) Why should we not use a wet spoon to take out jam or pickle from a jar?
12. (a) Name three common moulds (other than *Mucor*) and state their colours.
    (b) Name six materials on which *Mucor* may be found.
13. With the aid of a simple diagram of *Mucor*, explain the meaning of the following terms: (i) mycelium; (ii) hypha; (iii) stolon; (iv) sporangiophore; (v) sporangium; (vi) spore; and (vii) zygospore.
14. Briefly describe the possible modes of reproduction in *Mucor*.
15. How are fungi and bacteria 'friends of the agriculturist'?
16. Discuss nutrition and respiration in yeast.
17. 'Yeast is commercially and industrially very useful to us.' Substantiate this statement.
18. In what ways are fungi harmful to human beings?

SECTION 3

19. Draw a very simple diagram of a flowering plant and indicate the following parts: root system; shoot system; main root; lateral roots; root cap; root hairs; main stem; lateral branches; leaves; nodes; and internode.

20. Formulate a table to show the main function of each of the following: root hairs; lateral branches; leaves; flowers; axillary bud; and terminal bud.
21. Sketch a simple leaf (one which you may pluck from a plant in your garden). Observe and label in your diagram: petiole; lamina; mid-rib; and veins.
22. Pluck a flower from a plant in your garden and observe the following parts: pedicel; thalamus; sepals; petals; stamens; anthers; pistil; and style. Sketch the flower you have plucked and label all the parts you have observed.
23. Describe the process of pollination. Why is it essential to the life of a flowering plant?
24. What is fertilisation? State what happens to a flower after pollination and fertilisation have occurred.

CHAPTER 10

The World of Animals

SECTION 1: THE MAJOR GROUPS OF ANIMALS

Numerous species of animals are known today. The entire animal kingdom can be divided into two basic types: **unicellular animals**, i.e., the one-celled animals such as *Amoeba*, and **multicellular animals**, i.e., the animals with a large number of cells in their body such as earthworms, cockroaches, fishes, frogs, cats, monkeys, and human beings. Multicellular animals are of two types: those with a backbone and those without one. Animals which possess a backbone or a vertebral column are called **vertebrates**. Examples of vertebrates are fish, frogs, lizards, birds, monkeys, snakes, and human beings. Animals which do not possess a backbone or vertebral column are called **invertebrates**. Examples of invertebrates are starfish, snails, lobsters, crabs, insects, and worms.

For the sake of convenience, we classify animals into basic groups called **phyla** (singular **phylum**). Those animals which have similar structures and functions are placed in the same phylum.. Each phylum is subdivided into smaller groups such as class, order, family, genus, and species for more specific knowledge. The major phyla of the animal kingdom are as follows:

Invertebrates

(i) **Phylum Protozoa:** e.g., *Amoeba*, *Paramecium*, malarial parasite.
(ii) **Phylum Porifera:** e.g., sponges.
(iii) **Phylum Coelenterata:** e.g., jellyfish, *Hydra*, coral.
(iv) **Phylum Platyhelminthes:** e.g., flatworms (like liver-fluke and tapeworm).
(v) **Phylum Nemathelminthes:** e.g., roundworms (like hookworm and filaria worm).
(vi) **Phylum Annelida:** e.g., segmented worms (like earthworm and leech).
(vii) **Phylum Arthropoda:** e.g., centipede, millipede, spider, scorpion, prawn, cockroach.
(viii) **Phylum Mollusca:** e.g., snail and octopus.
(ix) **Phylum Echinodermata:** e.g., starfish and sea urchin.

Vertebrates

Phylum Chordata: e.g. fish, lizard, turtle, tortoise, snake, bird, human being, horse, and dog.

Animals belonging to the first phylum are all unicellular and are called **protozoans** [Figs. 10.1

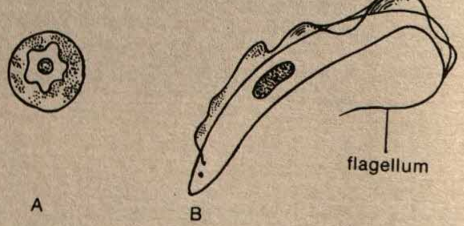


FIG. 10.1 **Some protozoans: A: *Plasmodium* and B: *Trypanosoma***

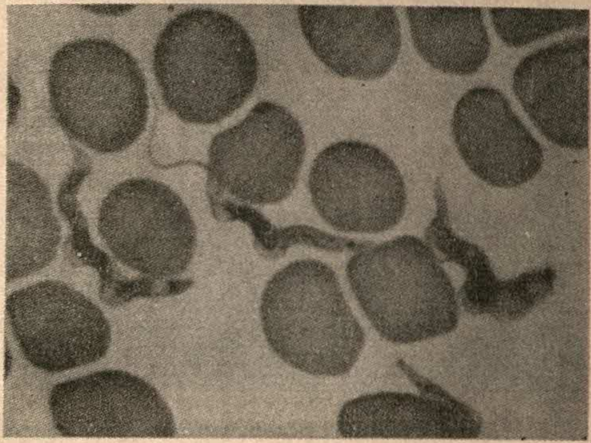


FIG. 10.2 Movement by *Trypanosoma*

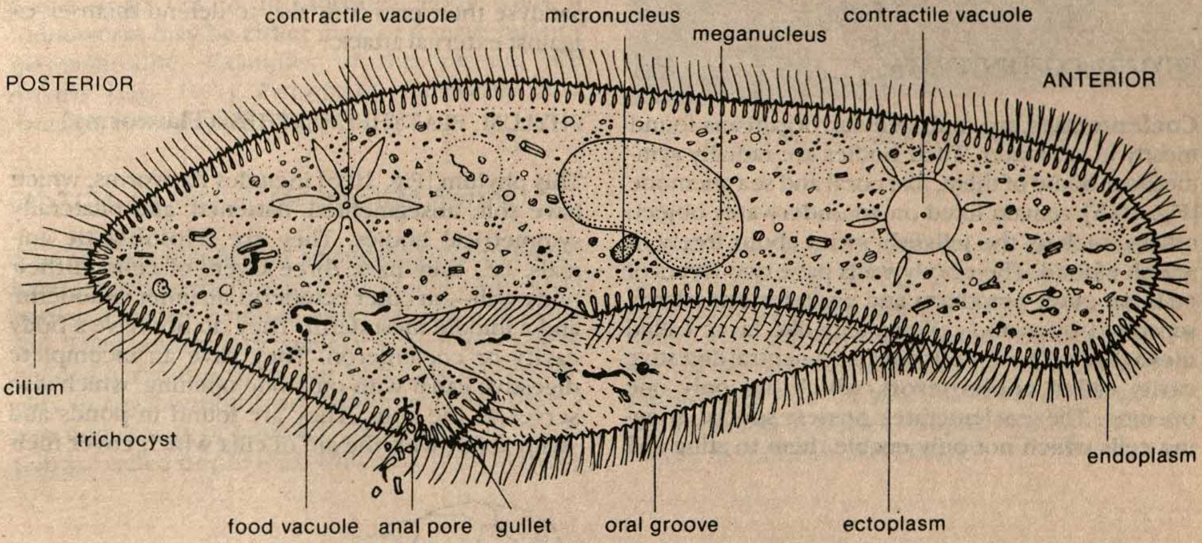


FIG. 10.3 Structure of *Paramecium*

and 10.2]. Animals belonging to the other nine phyla are all multicellular and are called **metazoans**.

We shall now describe the general characteristics of these ten phyla.

PHYLUM PROTOZOA (**The First Animals**)

This phylum includes the simplest and the most primitive of all animals. All the members of this phylum are unicellular. They live as free organisms in water and damp soil, and also as parasites within the bodies of other animals. Some protozoans cause diseases: e.g., *Plasmodium* causes malaria; *Entamoeba* causes amoebic dysentery and *Trypanosoma* causes sleeping sickness. Some protozoans contain chloroplasts and manufacture their own carbohydrate food. For instance, plants such as *Euglena* and *Volvox*. For locomotion, some of them have finger-like pseudopodia, others have whip-like flagella or hair-like cilia. They generally form protective cysts to tide over unfavourable conditions of life. They reproduce asexually by fission. Other examples of protozoans are *Paramecium* [Fig. 10.3], *Arcella, Difflugia, Ceratium, Balantidium*, and *Vorticella*.

PHYLUM PORIFERA (**The Pore-bearing Animals**)

This phylum includes the sponges [Fig. 10.4], which are primitive, pore-bearing, multicellular

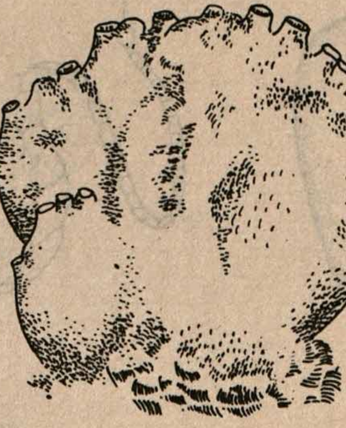


FIG. 10.4 Sponge

organisms. They are usually found in sea water, but occasionally in fresh water also. They fix themselves to an underwater object (such as a weed) and do not move about in search of food. Sponges are of various shapes, but essentially the body of a sponge is bag-like, consisting of a cavity enclosed by a wall that has numerous pores in it. Water seeps into the cavity through these pores, and, when in excess, is thrown out from a large opening at the top, known as the **osculum**. The cavity retains the microorganisms which enter along with the water, and the sponge feeds upon them. The body wall is strengthened by a framework of small **spicules** (hard, fibre-like needle-point structures) made of calcium and silicon. Examples of sponges are glass rope sponge and *Sycon*.

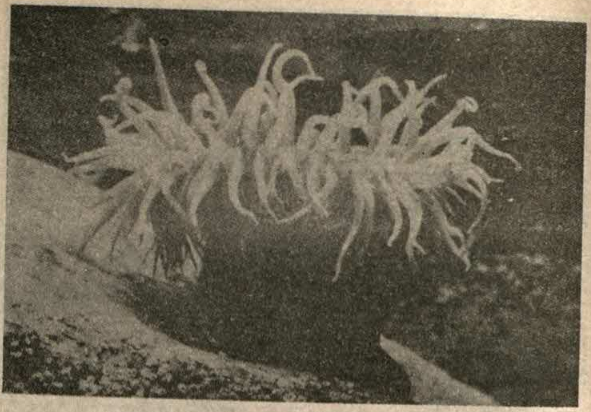


FIG. 10.5 Sea anemone

PHYLUM COELENTERATA

Coelenterates are multicellular organisms found mostly in sea water. Their bodies are radially symmetrical. Some of them, like coral and sea anemone [Fig. 10.5], remain fixed on an underwater object; others, such as the jellyfish, swim about freely in search of food. Their body walls have two layers of cells, an outer ectoderm and an inner endoderm, separated by a non-cellular jelly-like layer called **mesogloea.** These walls enclose a central digestive cavity called **coelenteron**, which has only one opening. The coelenterates possess special stinging cells which not only enable them to sting and paralyse their prey, but also to defend themselves against external attack.

PHYLUM PLATYHELMINTHES (**Flatworms**)

This phylum [Fig. 10.6] includes flatworms, which have soft, unsegmented, flattened, and bilaterally symmetrical bodies. They are **triploblastic** animals, i.e., they have three layers of cells in their body wall—an outer ectoderm, an inner endoderm, and a middle mesoderm. They do not have a body cavity or coelenteron. They have an incomplete digestive canal with only one opening, which also serves as the anus. They are found in ponds and swim about with the aid of cilia which cover their

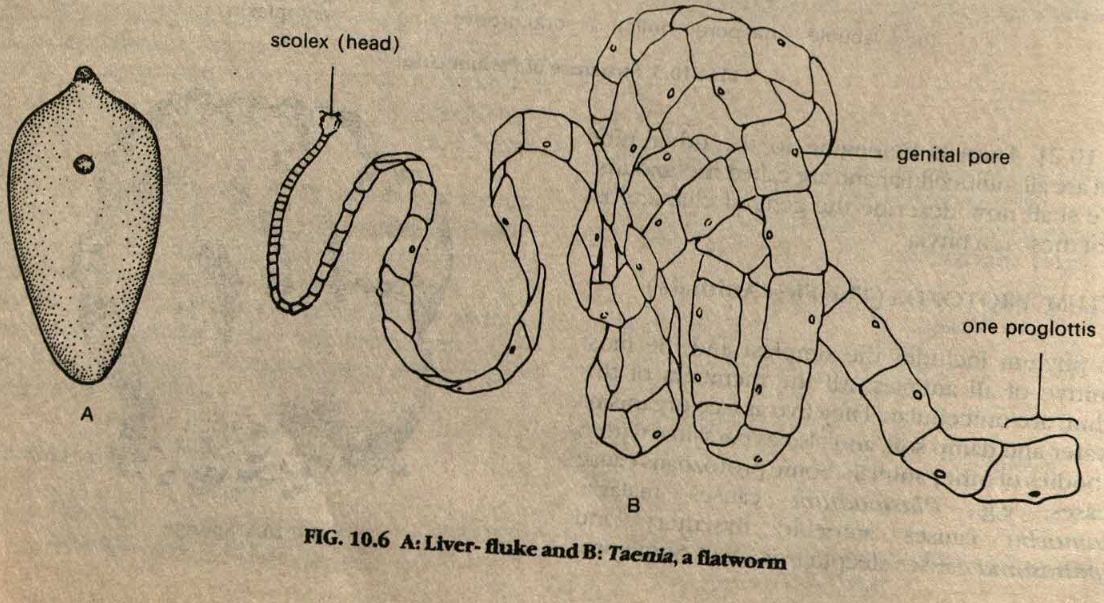


FIG. 10.6 A: Liver- fluke and B: *Taenia*, a flatworm

bodies. Some flatworms, such as *Planaria*, live independently, while others, such as liver-flukes and tapeworms, live as parasites. Usually, flatworms are hermaphrodites; i.e., both male and female reproductive organs are present in the same individual body.

PHYLUM NEMATHELMINTHES OR NEMATODA (**Roundworms**)

This phylum includes roundworms and threadworms. Such worms possess cylindrical, unsegmented bodies containing a complete digestive canal with two separate openings, a mouth, and an anus. These worms live freely in water and damp soil, and, as parasites, within the bodies of other animals. Unlike the Platyhelminthes, these worms possess a single sex in an individual body. Thus, a roundworm may be either male or female, but not hermaphrodite. Examples of this phylum are *Ascaris* [Fig. 10.7], *Entorbius* (pinworm), and *Ancylostoma* (hookworm).

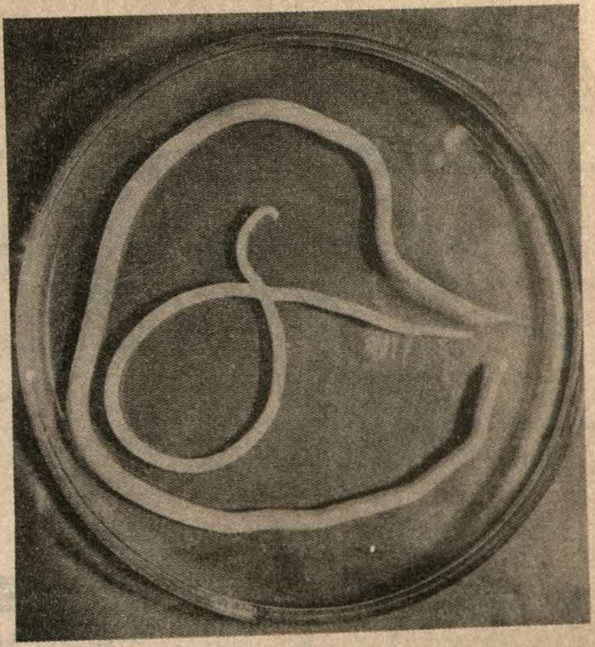


FIG. 10.7 ***Ascaris*, a roundworm**

PHYLUM ANNELIDA (**Segmented Worms**)

This phylum includes the segmented worms which have long bilaterally symmetrical and cylindrical bodies. They are found in water as well as in damp soil. They possess a circulatory system and a well-defined nervous system, and hence are more complex in organisation than flatworms. They have a true body cavity or **coelom**. Their organs of excretion are called **nephridia**, which are present in the coelom. A majority of these worms are hermaphrodite, but some do belong to separate sexes. Some, such as the leech, live as external parasites and suck blood from the bodies of higher animals. Others, such as the earthworm [Fig. 10.8], live in burrows in the soil and feed on small portions of animal and plant remains. Further examples of this phylum are *Nereis, Amphitrite*, and *Tubifex*.

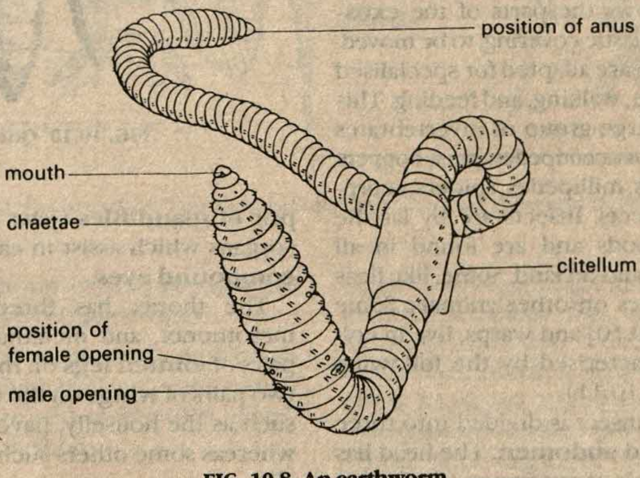


FIG. 10.8 An earthworm

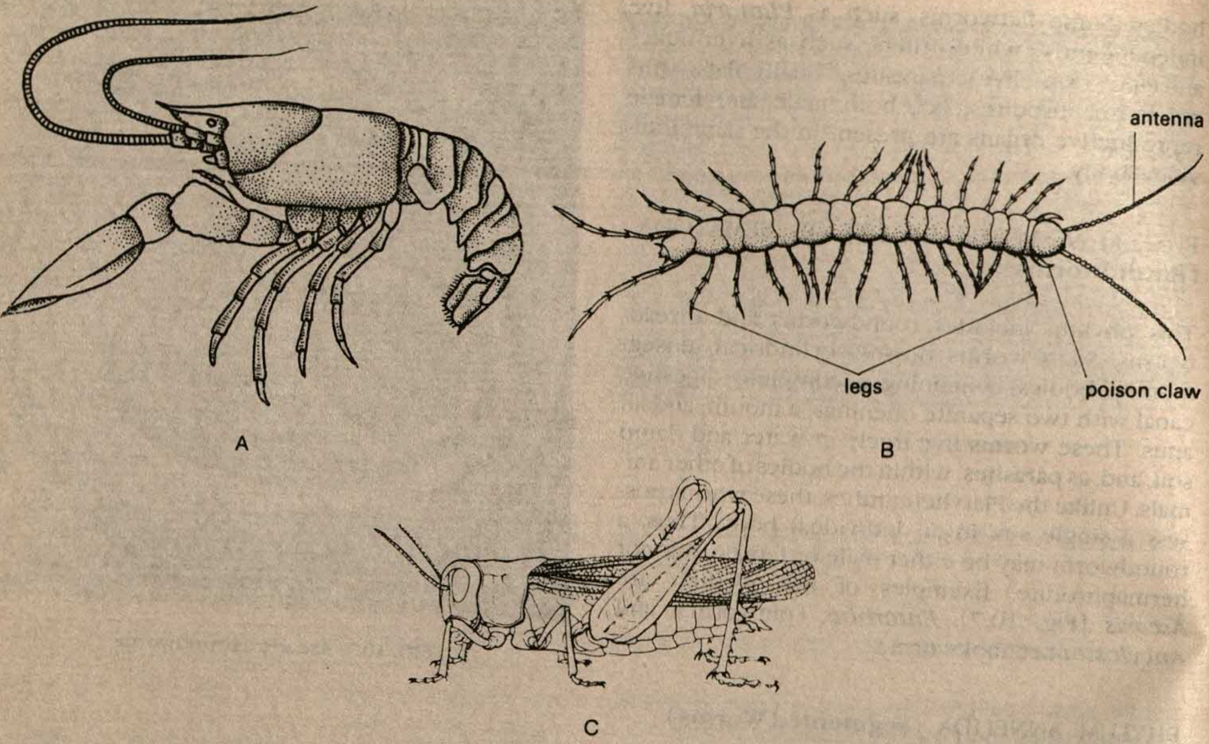


FIG. 10.9 A: Prawn; B: Centipede; and C: Grasshopper

PHYLUM ARTHROPODA (Joint-footed Animals)

Arthropods have a body that is bilaterally symmetrical. The body consists of segments. A thin and flexible membrane allows the parts of the **exoskeleton**, or the hard, inelastic covering, to be moved. Parts of the exoskeleton are adapted for specialised functions like swimming, walking, and feeding. This phylum forms a very large group of invertebrates and includes crabs, prawns, centipedes, grass-hoppers [Fig. 10.9 (a-c)], lobsters, millipedes, spiders, scorpions, mites, and all insects. Insects are by far the commonest of arthropods and are found in all habitats in water, in air, and on land. Some, like fleas and lice, live as parasites on other animals. Some others, like bees [Fig. 10.10] and wasps, live in colonies. Insects are characterised by the following important features [Fig. 10.11].

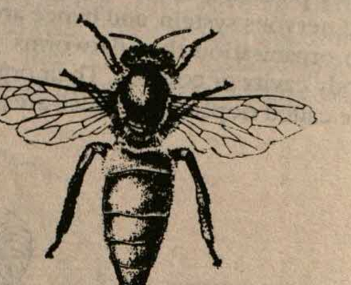


FIG. 10.10 Queen honey bee

First, the body of an insect is divided into three parts: **head, thorax,** and **abdomen**. The head has several appendages: a pair of **antennae** (feelers), a pair of **mandibles** (jaws), two pairs of **maxillae** (organs which assist in eating food), and a pair of **compound eyes**.

The thorax has three segments—prothorax, mesothorax, and metathorax—which bear three pairs of **jointed legs** on the lower side, and usually two pairs of **wings** on the upper side. Some insects, such as the housefly, have only one pair of wings, whereas some others such as lice have no wings at all.

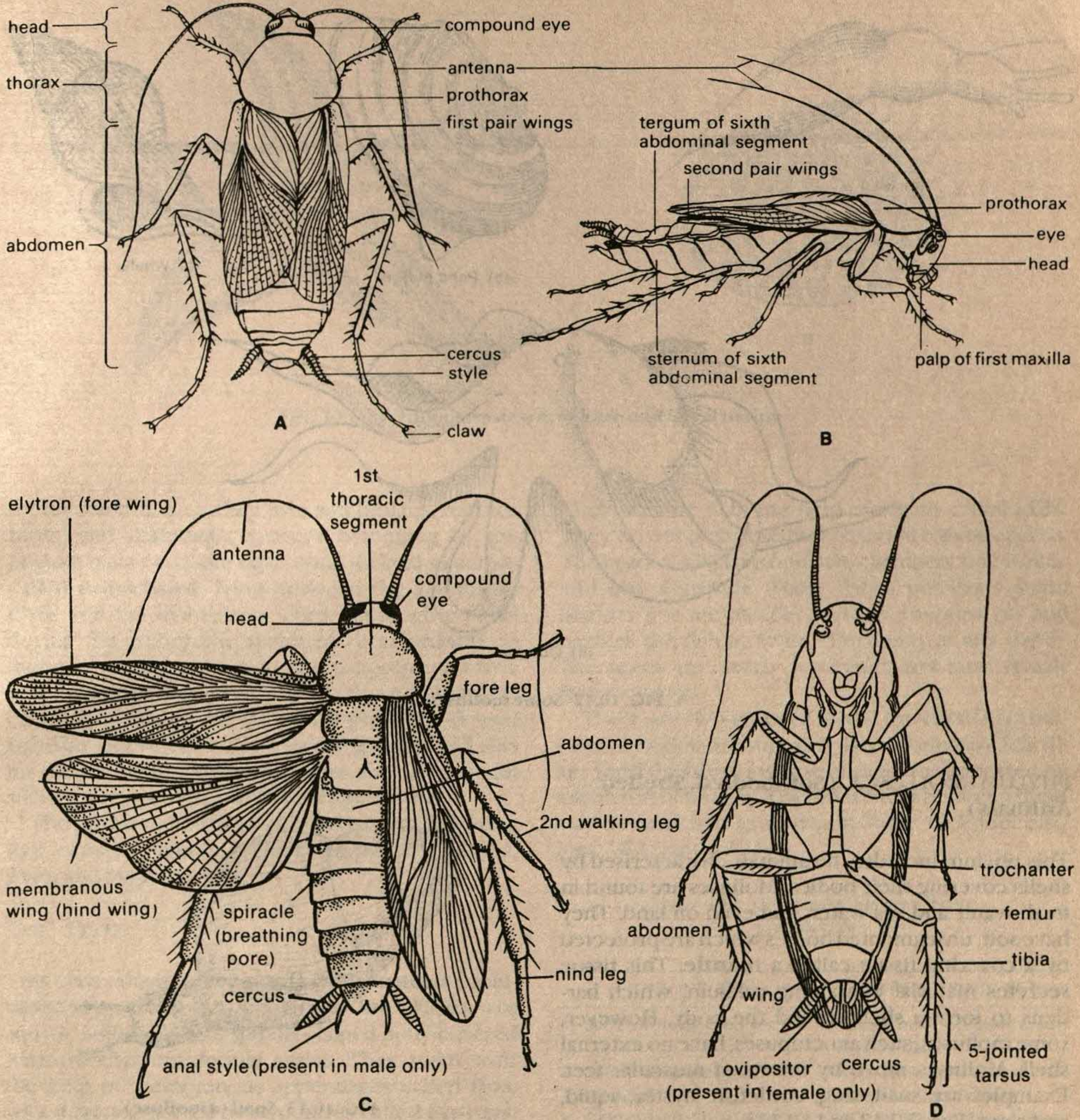
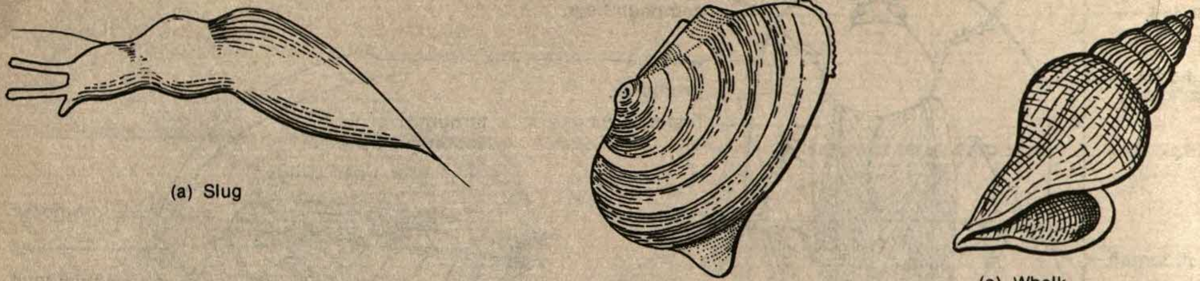


FIG. 10.11 Cockroach: A: Top view; B: Side view; C: Dorsal view; and D: Ventral view

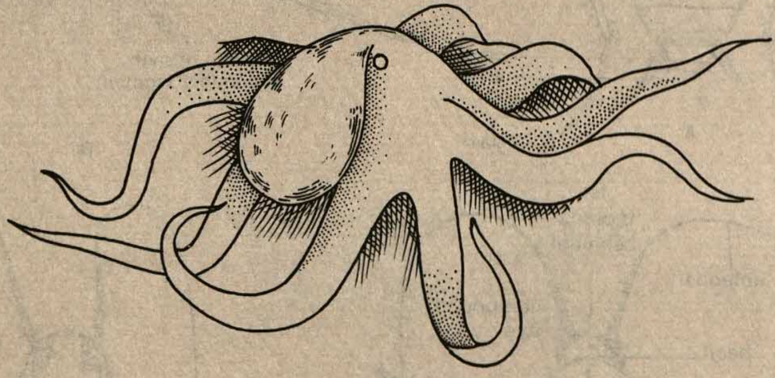
The abdomen is made up of several segments similar to each other. It has no appendages.

Insects breathe by means of paired openings called **spiracles** or **stigmata** which lead into a network of air tubes called **tracheae** and **tracheoles**, distributed over the whole of the body.

Insects are also characterised by the existence of separate sexes among them. Examples of insects are cockroach, silver fish, dragon fly, grasshopper, housefly, mosquito, honey bee, wasp, lice, bugs, butterflies, moths, termites, fleas, beetles, and so on [Figs. 10.10 and 10.11]. Insects have a body cavity called **haemocoele** which is filled with colourless blood. Their organs of excretion are the Malpighian tubules.



(a) Slug (b) Pond mussel (c) Whelk



(d) Octopus

FIG. 10.12 Some molluscs

PHYLUM MOLLUSCA (**Soft-bodied, Shelled Animals**)

This phylum includes the animals characterised by shells covering their bodies. Molluscs are found in fresh water and sea water, and even on land. They have soft, unsegmented bodies which are protected by a covering tissue called a **mantle**. This tissue secretes material containing calcium, which hardens to form a shell around the body. However, some molluscs, such as octopuses, have no external shell. Molluscs move by means of muscular feet. Examples are snail, slug, cuttlefish, oyster, squid, and clam [Figs. 10.12 and 10.13].

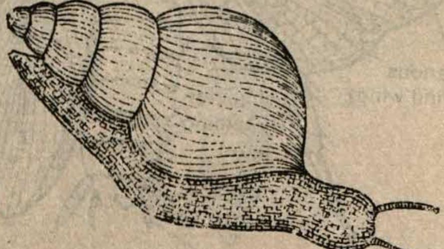


FIG. 10.13 Snail (a mollusc)

PHYLUM ECHINODERMATA (**Spiny-skinned Animals**)

This phylum includes animals with a radially symmetrical and unsegmented body protected by prickly or spiny skin, such as starfish and sea urchin [Fig. 10.14]. They are all found in sea water. They have an outer skeleton which is a framework of calcareous (calcium-containing) plates or spines embedded in the body wall. Most echinodermates move sluggishly, with the aid of tube feet projecting from the body. Some are even completely stationary. Other examples of this phylum are sea cucumber and sea lily.

PHYLUM CHORDATA

This phylum consists of all the animals with a ver-

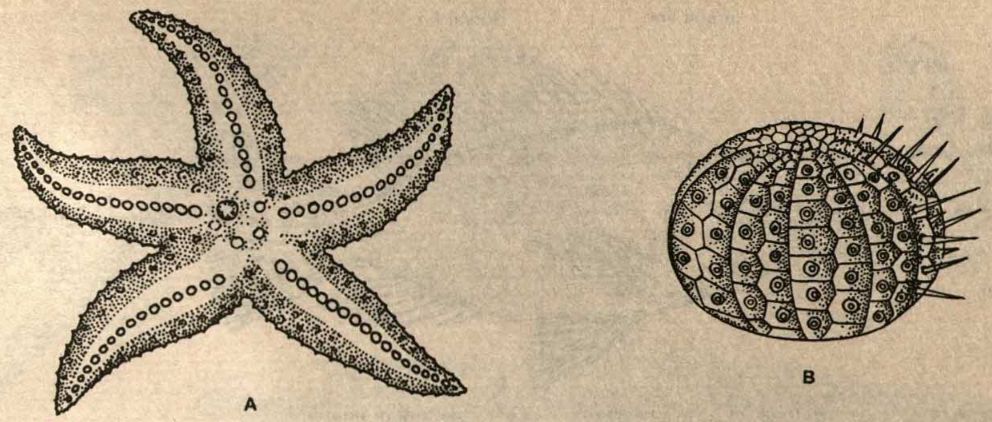


FIG. 10.14 Echinodermates: A: Starfish and B: Sea urchin

tebral column, including fish, amphibians, reptiles, birds, and mammals. Animals belonging to this phylum have a rod-like supporting skeletal structure, called **notochord**, lying between the alimentary canal and the main nerve cord. Although present during the embryonic stages of all **chordates**, in higher chordates, the notochord is replaced by a vertebral column. Consequently, these animals are called vertebrates. All chordates possess a **dorsal tubular nerve chord** and paired gills and gill slits for breathing. In higher chordates, the gills and gill slits are present only during embryonic life.

The phylum Chordata is divided into the following five classes, namely, Pisces, Amphibia, Reptilia, Aves, and Mammalia.

CLASS PISCES

This class consists of the **poikilothermous** (cold-blooded) vertebrates known as fish. Fishes are aquatic animals with a spindle-shaped body covered with overlapping dermal scales. They swim with the help of membranous appendages called **fins**, which are supported by structures called **fin-rays**. They breathe with the help of organs called **gills**. They do not possess either external ears or eyelids. The heart of a fish has only two chambers, one auricle and one ventricle. Many fishes possess a swim bladder (or air bladder) which contains gas and enables the fish to swim effortlessly at any depth. The sexes are clearly separated, and most female fishes lay eggs.

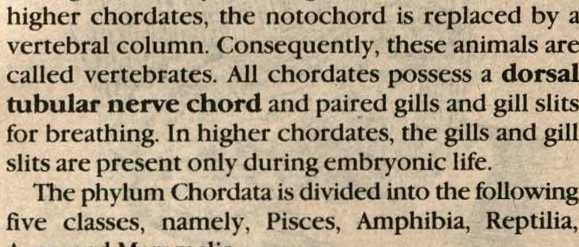


FIG. 10.15 Shark—a cartilaginous fish

There are two types of fishes: the **cartilaginous** (whose bodies are supported by a skeleton of cartilage) and the **bony** (whose bodies are supported by a skeleton of bones). The differences between them may be tabulated as shown in Table 10.1. [See also Figs. 10.15 and 10.16.]

TABLE 10.1 DIFFERENCES BETWEEN BONY AND CARTILAGINOUS FISH

BONY FISH	CARTILAGINOUS FISH
1. Skeleton made of bones.	Skeleton made of elastic tissue called cartilage.
2. Mouth set at the tip of the head.	Mouth set on the **ventral** (lower side) of the head.
3. Gills and gill slits covered with a bony flap called **operculum**, and, therefore, not externally visible.	Gills and gill slits not covered with operculum, and therefore externally visible.
4. Found in both sea water and fresh water.	Found only in sea water.
5. Fertilisation is external.	Fertilisation is internal.

Examples of common cartilaginous fishes are dog fish, sawfish, electric ray, sting ray, and hammer-headed shark. Examples of common bony fishes are sardines, herring, salmon, pomfret, seahorse, trout,

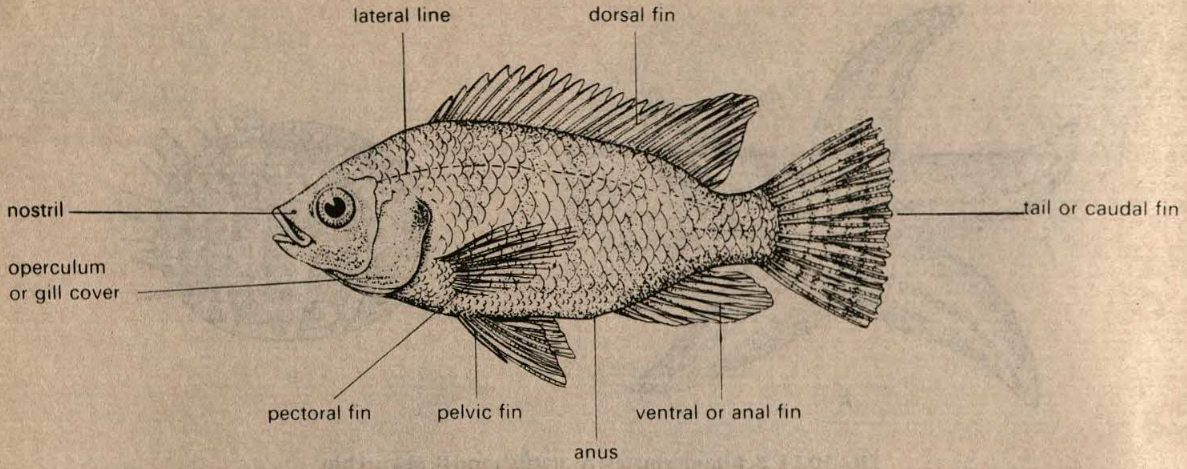


FIG. 10.16 A bony fish

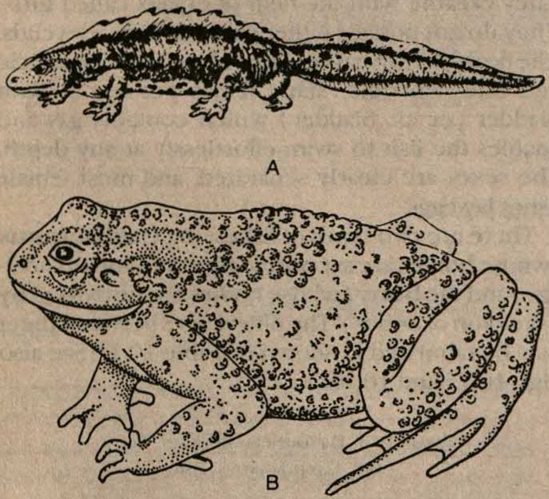


FIG. 10.17 A: Newt and B: Common toad

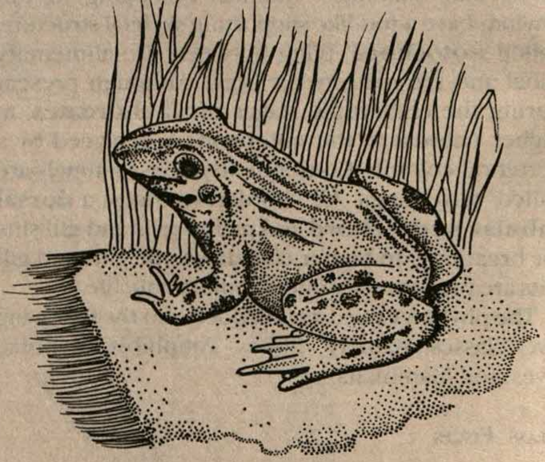


FIG. 10.18 A frog ·

flying fish, *bhetki*, angler fish, climbing perch, Rohu and *Tilapia*.

Class Amphibia

This class of chordates includes vertebrates such as frogs, newts [Fig. 10.17], toads and salamanders. These are all poikilothermous (cold-blooded) and live in water at the larval stage, but can live both on land and in water at the adult stage. They have skins which are thin, glandular, and without scales. These vertebrates have two pairs of limbs which enable them to walk, jump, and swim. They have three organs for breathing, which may be simultaneously used: the skin, the lining of the mouth cavity, and the lungs. The larvae of amphibians, called **tadpoles**, breathe through gills. They have hearts with three chambers, i.e., two auricles and one ventricle. In this class, the sexes are clearly separated and the females lay eggs. Table 10.2 lists some of the major differences between frogs and toads so as to highlight the variations in their physical structures [see also Fig. 10.18].

Class Reptilia

This class also includes poikilothermous vertebrates,

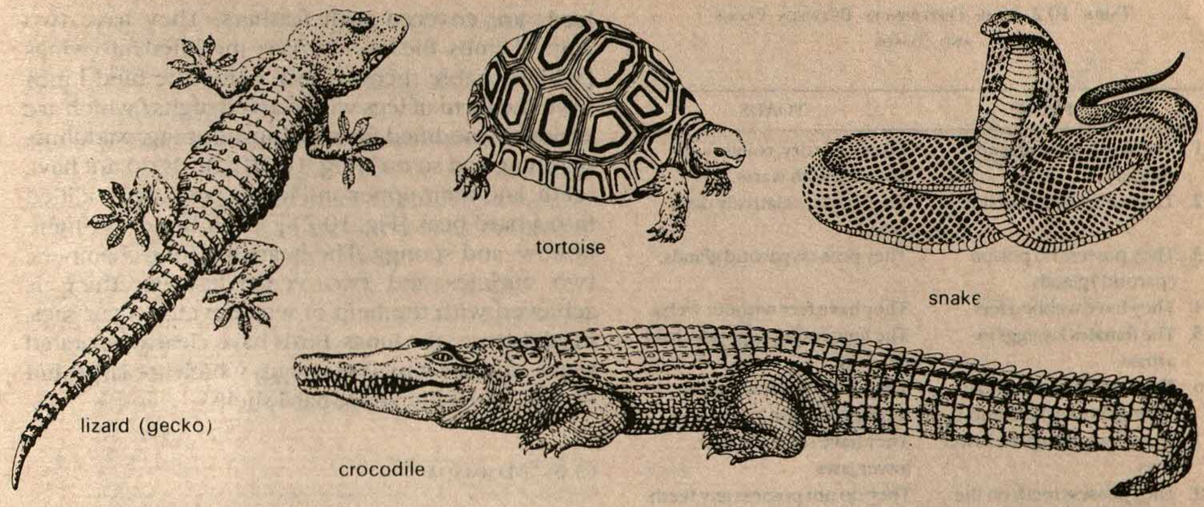


FIG. 10.19 Various reptiles

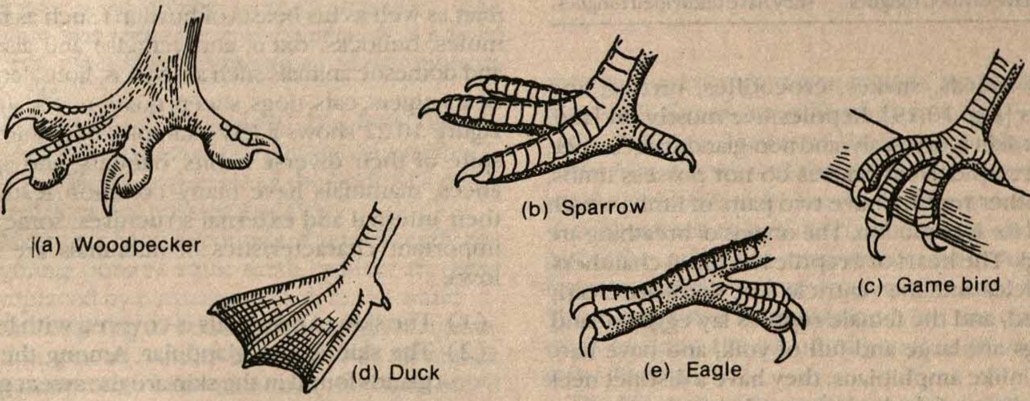


FIG. 10.20 Different types of birds' feet

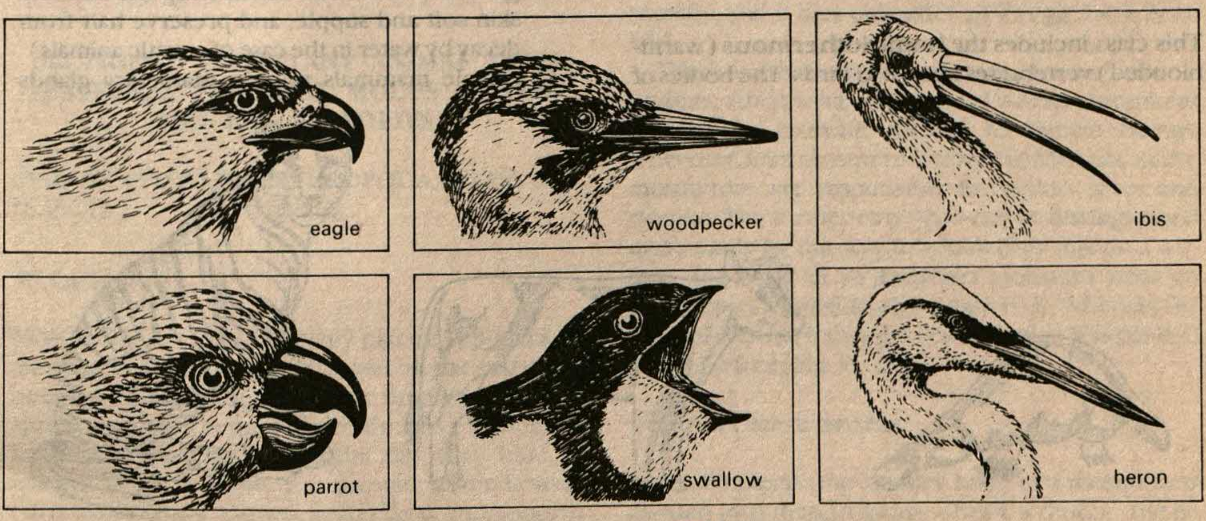


FIG. 10.21 Different types of birds' beaks

Table 10.2 Some Differences Between Frogs and Toads

FROGS	TOADS
1. The skin is smooth and slippery.	The skin is dry, rough, and covered with warts.
2. They are mainly aquatic.	They prefer relatively dry land.
3. They possess no poison (parotid) glands.	They possess parotid glands.
4. They have webbed feet.	They have feet without webs.
5. The females lay eggs in a mass.	The females lay eggs in a chain or string.
6. They are diurnal (awake during the day) creatures.	They are nocturnal (awake during the night) creatures.
7. They have triangular lower jaws.	They have semi-circular lower jaws.
8. They possess teeth on the upper jaw.	They do not possess any teeth.
9. They have divided tongues.	They have undivided tongues.

such as lizards, snakes, crocodiles, turtles, and tortoises [Fig. 10.19]. Reptiles live mostly on land, and their skin is dry, scaly, and non-glandular. Further, scales are epidermal. Snakes do not possess limbs, but all other reptiles have two pairs of limbs which are used for locomotion. The organs of breathing are the lungs. The heart of a reptile has three chambers: two auricles and one ventricle. The sexes are clearly separated, and the female reptiles lay eggs on land. The eggs are large and full of yolk, and have hard shells. Unlike amphibians, they have a distinct neck and the digits of the limbs have claws.

Class Aves

This class includes the **homoiothermous** (warm-blooded) vertebrates known as birds. The bodies of birds are covered with feathers. They have two pairs of limbs: the forelimbs are modified into wings (which enable them to fly), while the hind limbs have the form of legs with clawed digits (which are variously modified for walking, hopping, waddling, perching and so on) [Fig. 10.20]. Birds do not have teeth, and their upper and lower jaws are modified into a hard beak [Fig. 10.21]. Their bones are light, hollow, and spongy. The heart has four chambers: two auricles and two ventricles. Breathing is achieved with the help of well-developed air sacs, in addition to the lungs. Birds have clearly separated sexes, and the females lay eggs which are large, full of yolk, and which have hard shells.

Class Mammalia

This is the most familiar class of animals. It includes man as well as his beasts of burden (such as horses, mules, bullocks, oxen, and camels) and also wild and domestic animals such as hyenas, lions, leopards, bears, tigers, cats, dogs, sheep, goats, cows, and pigs. Figure 10.22 shows a few examples of mammals. In spite of their diverse habits, habitats, and appearances, mammals have many common features in their internal and external structures. Some of the important characteristics of mammals are as follows:

(1) The skin of mammals is covered with hair.
(2) The skin is also glandular. Among the many glands found in the skin are the **sweat glands** (which aid in excretion and in the control of body temperature), and the **sebaceous glands** (whose secretions keep the hair and skin soft and supple, and preserve hair from decay by water in the case of aquatic animals).
(3) Female mammals possess mammary glands

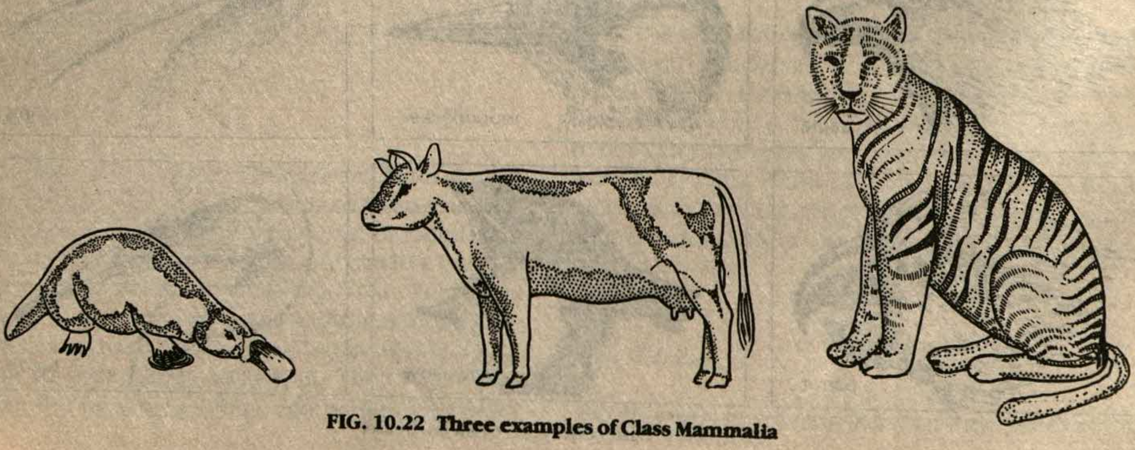


FIG. 10.22 **Three examples of Class Mammalia**

which produce the milk on which the offspring are fed.

(4) The external ears of mammals have fleshy lobes, called **pinnae**.

(5) Mammals possess four limbs. Generally, each limb has five digits, which are variously adapted for different methods of locomotion. The digits have horny claws, nails, or hooves, and often have fleshy pads.

(6) Mammals breathe through their lungs.

(7) Mammals possess a muscular diaphragm which divides the cavity of the body into a **thoracic cavity** present in the **thorax** (chest cavity) and an **abdominal cavity** present in the **abdomen**.

(8) Mammals are homoiothermic (warm-blooded) or stenothermous (i.e., they cannot withstand wide variations of temperature in their surroundings). They regulate their body temperature and maintain it at a fixed level above the temperature of the environment.

(9) The heart of a mammal has four distinct chambers: two auricles and two ventricles.

(10) A red blood corpuscle in the body of a mammal does not possess a nucleus.

(11) Mammals have two kinds of sets of teeth: the young possess milk teeth, which are later replaced by permanent teeth in the adult.

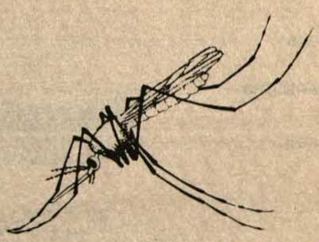
(12) An offspring of a mammal undergoes a gestation period within the uterus of its female parent. Only two mammals, the duck-billed platypus and the spiny anteater, lay eggs.

SECTION 2: IMPORTANT ANIMAL TYPES (EXTERNAL FEATURES, MODES OF LIFE, AND LIFE HISTORIES)

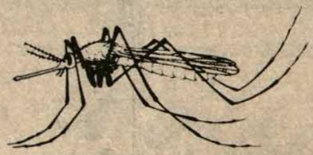
INSECTS (PHYLUM ARTHROPODA, CLASS INSECTA)

Mosquito

Mosquitoes are found in many places: in houses, in gardens, in fields, near drains, and on the surface of ponds. They abound during the monsoon and the spring seasons. They are generally active during the hours of darkness. During the day they hide in hedges, in the hollows of trees, and within houses (in almirahs, dark corners, under beds, and beneath clothes). The sexes are separate among mosquitoes, and the common food of both males and females is the nectar of flowers and the juices secreted by plants. However, the female mosquito also sucks blood from vertebrate animals. Not only is it painful to be bitten by the female mosquito, but it is also dangerous to health. The female mosquito may carry the microbes responsible for four human diseases: malaria, yellow fever, dengue, and filariasis. These microbes are obtained by the mosquito while sucking the blood of people suffering from these diseases.



Anopheles



Culex

FIG. 10.23 Body position of mosquitoes at rest

The life-span of the male mosquito is about three weeks. It dies after it has fertilised the female. The female's life-span ranges from four weeks to several months, and it dies only after all its eggs have been laid.

There are three important types (genera) of mosquitoes: *Anopheles*, *Culex*, and *Aedes*. *Anopheles* mosquitoes transmit malaria to human beings, whereas *Culex* mosquitoes transmit filariasis. *Aedes* mosquitoes are responsible for yellow fever and dengue. The former two types can be distinguished quite easily by the way in which they rest on a surface. The body of an *Anopheles* mosquito rests on a surface at a considerable angle to it, whereas the body of a *Culex* mosquito rests more or less parallel to the surface [Fig. 10.23].

External Characteristics

As in all insects, the slender body of a mosquito is divided into three regions: a head, a thorax, and an abdomen.

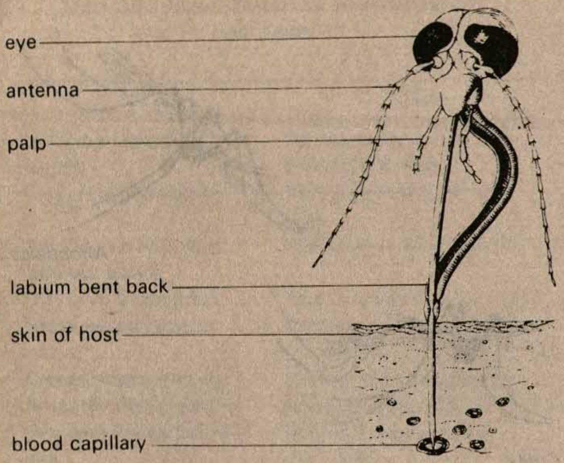


FIG. 10.24 Head of female mosquito in the act of biting

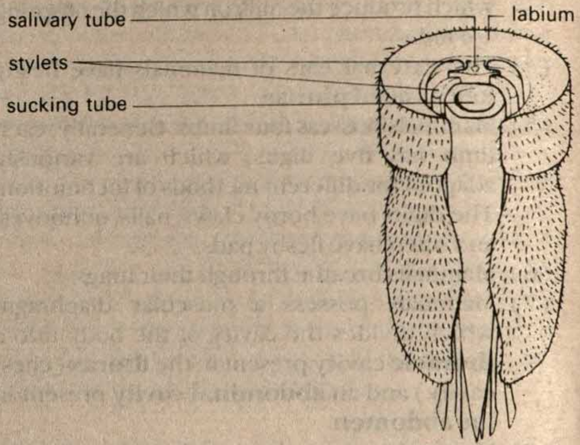


FIG. 10.25 Section through mouth parts of mosquito; highly enlarged

The **head** is rounded, and is very mobile since it is connected to the thorax by a very slender neck. Located on the head are two large bean-shaped **compound eyes** and two **antennae** (feelers). The antennae are covered with fine hair; these are more numerous in the male than in the female which gives the antennae a more bushy appearance. The head also bears two **maxillary palps** and a **proboscis**. The female uses the proboscis to penetrate the skin of a host and suck its blood [Figs. 10.24 and 10.25].

The **thorax** is slightly arched and has three segments: **prothorax, mesothorax**, and **metathorax**. The mesothorax is the largest of these segments and bears the first pair of wings. These wings beat at the rate of 300 times per second during flight and produce the droning sound we are familiar with. As in the case of the housefly, the second pair of wings is reduced to a pair of knob-like **halteres** which help in balancing the mosquito during flight. Three pairs of jointed legs are attached to the ventral side of the thorax. Each leg has a pair of **claws** and a pad called **pulvilus** at its end. The thorax also bears two pairs of **spiracles** (breathing pores).

The **abdomen** is long and narrow and consists of nine segments. However, only the fourth to the eighth segments are clearly visible, and each carries a pair of spiracles for breathing. The anus is located ventrally on the eighth segment and the genital aperture is located ventrally on the last segment.

The Life History of the Anopheles Mosquito

The **eggs** of the female *Anopheles* mosquito are white at first, but turn dark grey later. The female lays about 40–100 eggs at a time on the still water of ponds, pools, ditches, drains or swamps either during the night or early in the morning. Each egg has a small air space on either side to keep it floating on the surface of water. The eggs do not stick together.

The eggs of *Culex* are cigar-shaped. The female uses its legs to arrange the eggs while laying, and glues them together side by side to form 'rafts' which float on the water. Air bubbles are locked between the eggs, so they remain afloat even when the water is disturbed. Within two to three days of being laid, the eggs hatch. A larva emerges from the rear end of each egg [Fig. 10.26].

The **larva** is less than 1 mm in length when it emerges from the egg. It has a distinct head, a thorax and an abdomen. It bears a pair of short antennae, a pair of compound eyes, chewing mouth parts and a pair of feeding brushes. It feeds on microscopic plants in the water with the help of feeding brushes.

The thorax does *not* have three distinct segments (prothorax, mesothorax and metathorax). It also does not bear any legs and wings. Three tufts of long bristles are present on either side of the thorax and protect the larva from being eaten up by fishes.

The abdomen is long and slender and bears nine segments, each with a tuft of bristles which protect the larva again from being eaten up by fishes. The eighth abdominal segment bears a short conical breathing siphon which has a pair of openings called spiracles through which the larva breathes. The siphon is periodically raised to the surface of water to breathe in air. Water cannot enter the siphon because its end is protected by hinged flaps. The skin

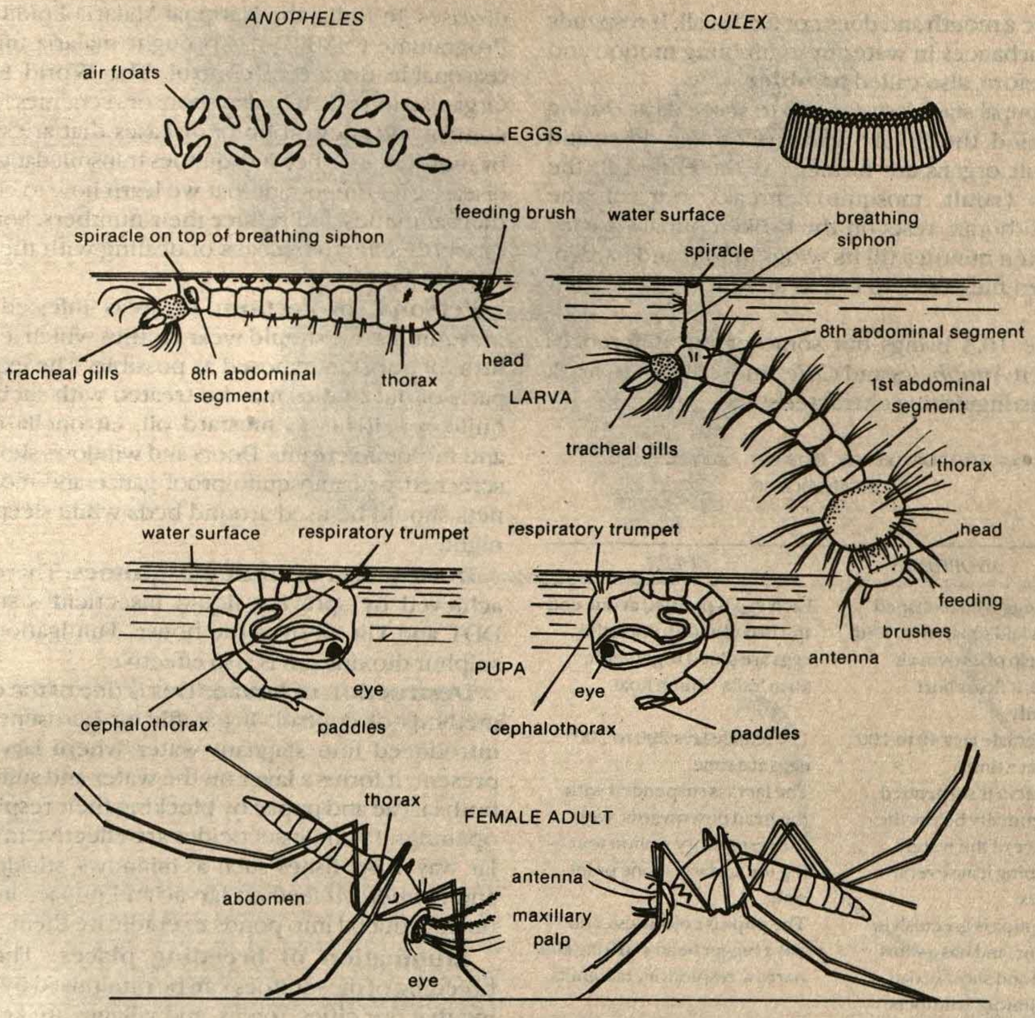


FIG. 10.26 Various stages in the life histories of two types of mosquitoes

around the spiracles is also water repellent and helps prevent entry of water into the spiracles. The tufts of bristles on the ninth abdominal segment are longer and they help the larva in swimming. At the end of the abdomen lies the anus, surrounded by four leaf-like tracheal gills, which are also used for breathing.

The larva floats parallel to and just below the surface of water. The larval stage lasts for about fourteen days. During this period, the larva moults (sheds its skin) three to four times, and grows larger with each moulting. A full-grown larva may measure up to 1 cm in length. Since the larva swims about actively by means of wriggling movements of its long abdomen, it is also called a **wriggler**.

The **pupa** is shaped like a comma. Its head and thorax are fused together to form a **cephalothorax**. The pupa floats just below the surface of water, with the cephalothorax uppermost. On its back are two **respiratory trumpets** which penetrate the surface of water and admit air from the atmosphere through the openings at their tips. The **puparium** (pupal case) is transparent, and through it developing compound eyes, antennae, proboscis, and wings may be seen on the cephalothorax. The abdomen is slender, curved, and segmented, and bears tufts of bristles. A pair of leaf-like **paddles** or tail fins on the last abdominal segment enable the pupa to swim about. The pupa is very active and swims about vigorously by flicking its abdomen. The pupa does not have a mouth and does not feed at all. It responds to disturbances in water by a tumbling motion and is, therefore, also called **tumbler**.

The pupal stage lasts for two to seven days. During this period, the larval organs are broken down and the adult organs are formed. At the end of it, the **imago** (adult mosquito) breaks out of the cephalothorax, rests on the broken pupal case for five to ten minutes till its wings unfold and harden, and then flies away to live as an independent adult insect.

Table 10.3 brings out some of the differences between *Anopheles* and *Culex* mosquitoes to mark their distinguishing characteristics.

TABLE 10.3 DIFFERENCES BETWEEN *ANOPHELES* AND *CULEX* MOSQUITOES

ANOPHELES	*CULEX*
1. Each egg is boat-shaped and is laid separately. With the help of its own air space, it floats horizontally.	Each egg is pointed at one end and broad at the other; the eggs are glued together to form 'rafts' which float.
2. The female lays 40 to 100 eggs at a time.	The female lays 200 to 300 eggs at a time.
3. The larva is suspended horizontally below the surface of the water, touching it at several places.	The larva is suspended with the head downwards, with the respiratory siphon touching the surface at one point only.
4. The pupa is greenish in colour, and has a short head and short broad respiratory trumpets.	The pupa is colourless, and has a bigger head and long and narrow respiratory trumpets.
5. The abdomen of the pupa is sharply bent.	The abdomen of the pupa is less sharply bent.
6. The wings of the adult have spots on them.	The wings of the adult have no spots on them.
7. When at rest, the body is placed at an acute angle to the surface.	When at rest, the body is placed more or less parallel to the surface.
8. The body of the adult is slender and has delicate legs.	The body of the adult is stouter, with thicker legs.

The Control of Mosquitoes

On account of the role of mosquitoes as agents for the transmission of various diseases such as malaria, filariasis, yellow fever and dengue, they are of great importance from an economic point of view. The diseases affect millions of people throughout the world, particularly in tropical countries where huge funds are used to control and prevent these diseases. In India, the National Malaria Eradication Programme (NMEP) has brought malaria under a reasonable degree of control. The World Health Organisation (WHO) also sponsors schemes for the control and prevention of diseases that are spread by mosquitoes. Since mosquitoes transmit dangerous diseases, it is important that we learn how to control their activities and reduce their numbers. Some of the more effective means of dealing with them are as follows.

Personal protection: In areas infested with mosquitoes, we should wear clothes which leave as little of our skin exposed as possible. The exposed parts of our bodies may be treated with such mosquito repellents as mustard oil, citronella oil, or anti-mosquito creams. Doors and windows should be screened with mosquito-proof gauze and mosquito nets should be used around beds while sleeping at night.

Destruction of adult mosquitoes: This can be achieved by spraying liquid insecticides such as DDT and Flit all over the house. Fumigation with sulphur dioxide gas is also effective.

Destruction of larvae: This is one of the easiest methods of control. If paraffin or kerosene oil is introduced into stagnant water where larvae are present, it forms a layer on the water and suffocates both larvae and pupae by blocking their respiratory openings. Liquid insecticides are effective in a similar way. Also, fishes such as minnows, sticklebacks, and *Gambusia* feed on larvae and pupae, and may be introduced into ponds to eradicate them.

Elimination of breeding places: The very breeding of mosquitoes can be minimised by ensuring that our cities, towns, and villages are kept free of stagnant ponds, open drains, and ditches. Water should not be allowed to stand in lanes and streets, and the openings of drains should be cleaned regularly.

The Effect of a Mosquito Bite on the Skin

A mosquito penetrates the skin of a human being with its proboscis and sucks up blood with the aid of various parts of its mouth. Next, saliva is secreted into the wound. This saliva may contain microbes of a disease acquired by the mosquito while sucking the blood of an infected person. It may also contain a **symbiotic fungus** that lives in the mosquito's foodpipe and an enzyme called **anticoagulin**. This fungus produces carbon dioxide in the wound and this causes the irritation around a mosquito bite in our skin. The enzyme prevents our blood from

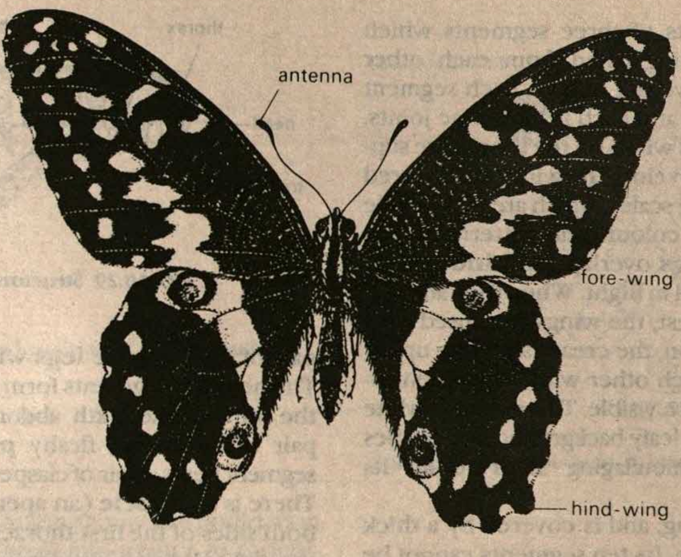


FIG. 10.27 Cabbage-white butterfly

being clotted while it is being sucked in by the mosquito. The area in our skin around the bite itches and swells up.

BUTTERFLY

Butterflies are perhaps the most brilliantly coloured insects. Butterflies are a common sight in gardens and fields, where they go in search of nectar. A species which is very common, especially in spring and early summer, is the **cabbage-white butterfly** [Fig. 10.27]. It has large wings with black patches, which are more prominent in the female.

Structure

As is common among insects, the body of the butterfly is divided into three segments. These parts cannot be easily distinguished from each other because the body is covered with hair. The three parts of the body are the head, the thorax, and the abdomen.

The head bears a pair of large **compound eyes** and three large **simple** eyes which are hidden beneath the thick hair on top of the head. It also bears two low, long, jointed antennae with small knobs at their ends, which constitute the sense organs of touch and smell. Since the butterfly feeds on the sweet nectar of flowers, its mouth parts are modified into a long proboscis. The proboscis is a tube formed by bringing together two long **processes** that have grooves along their inner surface [Fig. 10.28]. The proboscis is kept spirally coiled under the head when not in use; when required, it is rapidly extended to suck nectar.

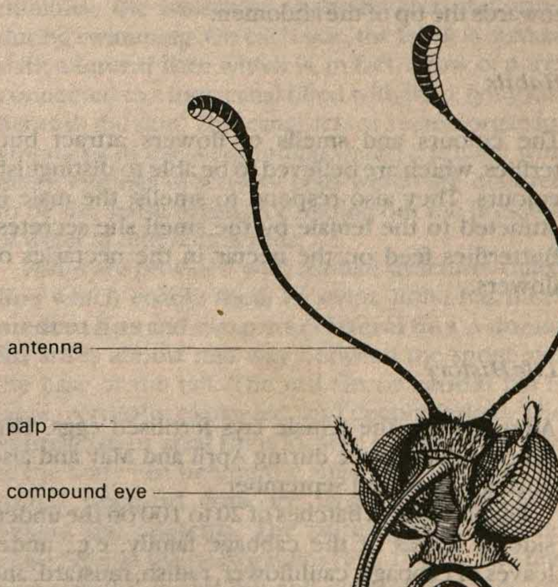


FIG. 10.28 Structure of head of butterfly

The **thorax** consists of three segments which cannot be easily distinguished from each other because of a thick covering of hair. Each segment bears one pair of legs, and each leg has nine joints. The two pairs of broad wings on the thorax are supported by networks of veins. The wings are covered with small, overlapping scales, which are responsible for the characteristic colours and patterns on the wings. The **fore wings** overlap the **hind wings**, and both pairs are used in flight. When the cabbage-white butterfly is at rest, the wings are raised over its back; in this position, the creamish-white upper surfaces lie against each other while the greenish-white lower surfaces are visible. This greenish-white colour blends with the leafy background and enables the butterfly in camouflaging itself from its enemies.

The abdomen is long, and is covered by a thick layer of scales and hair. Its ten segments cannot be distinguished from each other. The anus is situated towards the tip of the abdomen.

Habits

The colours and smells of flowers attract butterflies, which are believed to be able to distinguish colours. They also respond to smells; the male is attracted to the female by the smell she secretes. Butterflies feed on the nectar in the nectaries of flowers.

Life History

After mating, the female lays fertilised **eggs**. This process takes place during April and May and also during August and September.

Eggs are laid in batches of 20 to 100 on the underside of leaves of the cabbage family; e.g., under leaves of cabbage, cauliflower, radish, mustard, and so on. These eggs are attached to the leaves by means of a sticky secretion excreted by the female butterfly. They are shaped somewhat like bottles and have surfaces marked with ridges.

Larvae emerge when the eggs hatch, i.e., about ten days after being laid. Each larva, called a **caterpillar**, has a pair of powerful jaws which it initially uses to cut through the egg shell and later employs to eat cabbage leaves [Fig. 10.29].

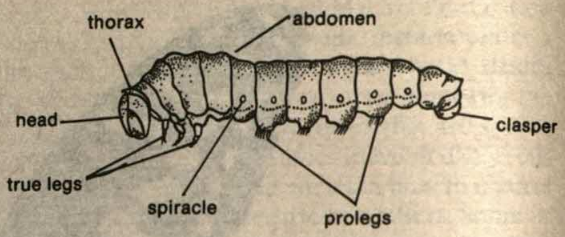


FIG. 10.29 Structure of caterpillar

The caterpillar is bluish-green in colour, and has black spots or patches all over its body. Its body is divided into a head and thirteen segments. The first three segments form the **thorax**, each bearing a pair of jointed **true legs** with claws at their ends. The next ten segments form the **abdomen**. Each of the third to the sixth abdominal segment bears a pair of unjointed, fleshy **prolegs**; the last body segment bears a pair of claspers similar to the prolegs. There is a **spiracle** (an aperture for breathing) on both sides of the first thoracic segment and each of the eight abdominal segments.

Behind the jaws, on the head, is a tube called the **spinneret**. The secretion from a special gland carried out by this tube hardens on exposure to air to form a silky thread. The caterpillar uses this secretion to grip slippery surfaces (e.g., wet leaves).

Moulting occurs for the first time when the caterpillar stops feeding; after a few days its skin splits down the back and the caterpillar wriggles out with a new skin. Moulting is followed by a rapid increase in size. After four moultings, the larva is fully grown and becomes about 3.5 cm long.

When the caterpillar is about thirty days' old, it moves from the cabbage plant to a dry, sheltered place. It climbs up a tree or a wall and settles there in a vertical position, with its head uppermost. It is attached to the tree or wall by means of a silky thread which it spins around its thorax. A group of hooks, known as the **cremaster** and located on the last segment of the abdomen, also help it to grip the surface. When it sheds its last skin, the larva becomes a **pupa**.

The pupa is shorter than the caterpillar and quite dissimilar [Fig. 10.30]. At first it is soft and pale, but soon it hardens and darkens. It possesses antennae, legs, proboscis, eyes, and wings like the adult. It does not feed and remains motionless for the next two or three weeks. During this period considerable breakdown and reorganisation of tissues take place within the pupa. The butterfly slowly develops, and, at the end of this period, the skin of the pupa splits down the back and the adult insect slowly works its way out. Its wings are crumpled and soft at first, but they soon expand and harden. The butterfly then begins to lead its adult existence.

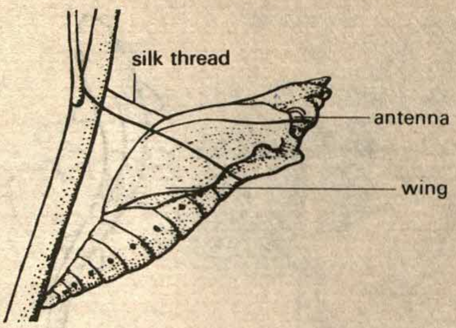


FIG. 10.30 Structure and position of pupa of butterfly

Merits and Demerits

As butterflies help in bringing about the pollination of flowers, they are of great importance to agriculturists. However, caterpillars eat up the leaves of plants of the cabbage family and cause extensive damage in gardens and fields, and have to be controlled.

FISH (PHYLUM CHORDATA, CLASS PISCES)

Labeo rohita (Rohu) is one of the commonest bony fishes found in fresh water in India. The back and the sides are bluish-black in colour while the underside is silvery or bluish-white. These colours make it difficult for one to see the fish in dark water from above and against a light sky from below, and thus camouflage it from enemies [refer to Fig. 10.16].

EXTERNAL CHARACTERISTICS

The spindle-shaped or streamlined body may be divided into a head, a trunk, and a tail. Let us discuss each part separately.

The **head** has an obtuse **snout**. The **mouth** is situated below the tip and has fleshy upper and lower lips. The **nostrils** are situated above the snout. They are not used for breathing but for smelling, since they lead into extremely sensitive organs of smell called **pits**. The fish can detect food from a considerable distance by using its sense of smell. The eyes are situated in the upper part of the head, just behind the nostrils. They are large, having rounded pupils without eyelids. The fish possesses no external ears; it uses an internal ear to detect vibrations in the water and as an organ of balance.

The **trunk** and the **tail** are covered with rows of overlapping scales [Fig. 10.31]. The scales are set at an angle in the skin and point backwards, so as to minimise the resistance of the body to the water during swimming. On each side, the trunk is marked with a **lateral line** which is, in fact, a row of pores connected to a long canal filled with fluid, lying just beneath the skin. This canal acts as a sense organ for vibrations in the surrounding water; it is lined with nerve endings of sensory cells which are believed to be the sense organs for finding out the pressure of water at different depths.

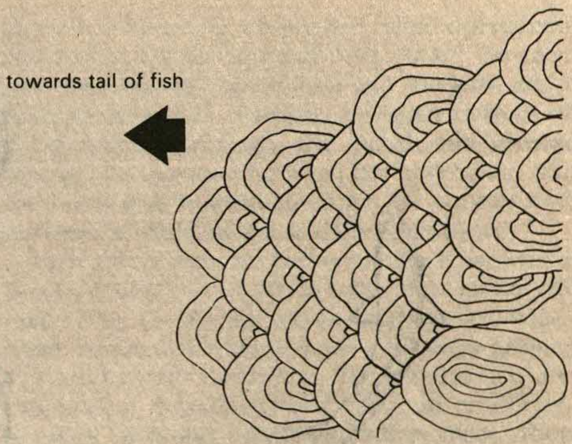


FIG. 10.31 Arrangement of scales on the body of bony fish

Fishes are provided with oar-like structures called **fins** which enable them to swim. Rohu has three **median fins** and two pairs of **lateral fins**. A **dorsal fin** arises almost mid-way between the snout and the base of the tail. The **tail fin** or **caudal fin** is large, vertically expanded, and deeply forked. The **ventral fin** or **anal fin** is located on the lower side of the body just behind the anus, near the tail. The paired **pectoral fins** are large, being situated behind the opercula. The paired **pelvic fins** lie close behind the pectoral fins [Fig. 10.16]. The fins give stability to the fish and control direction of movement during swimming. The sexes are separate in fish, and the urogenital opening lies just behind the anus, towards the tail.

LOCOMOTION

The fishes are always seen swimming actively in the water in which they live. The muscles on either side of the vertebral column contract in a series from head to tail and down each side alternately and cause a wave-like motion to pass along the entire length of the body. The greater weight and lesser flexibility of

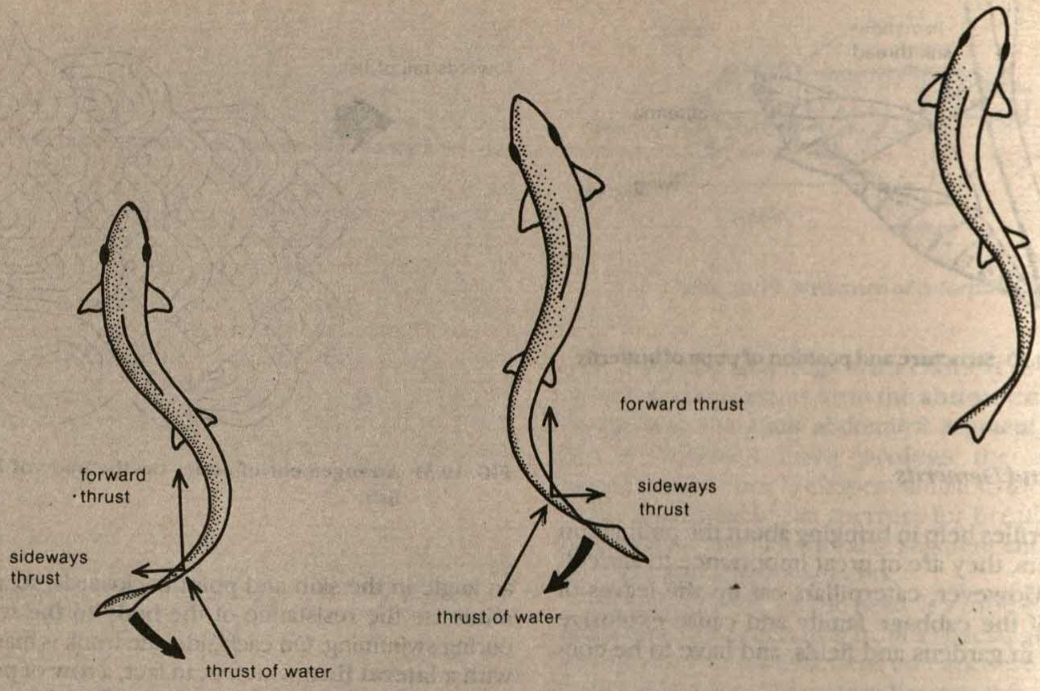


FIG. 10.32 Swimming movements in a fish

the head minimise movement of the head and lead to a far greater movement of the trunk and the tail as a result of these waves of contraction [Fig. 10.32].

Due to the contraction of muscles on one side of the body, different regions of the body push against the water sideways and backwards. Consequently, due to resistance of water against this thrust, the fish is pushed sideways and forwards, in a direction opposite to that of the thrust. When the muscles on the opposite sides of the body contract, the fish is similarly pushed sideways and forwards. The two sideways forces, being equal and opposite, are cancelled out and the sum of the two forward forces propels the fish forward.

Role of Fins in Swimming

The force to propel the fish forward is provided by the whole of the muscular body, and not by the fins, except the caudal fin. The main functions of the fins are to give stability and control the direction of movement during swimming [Fig. 10.33].

The sideways and backwards thrust of the caudal fin may provide as much as 40 per cent of the forward propulsive force.

The unpaired fins—dorsal, ventral, and anal—control the rolling and yawing movements.

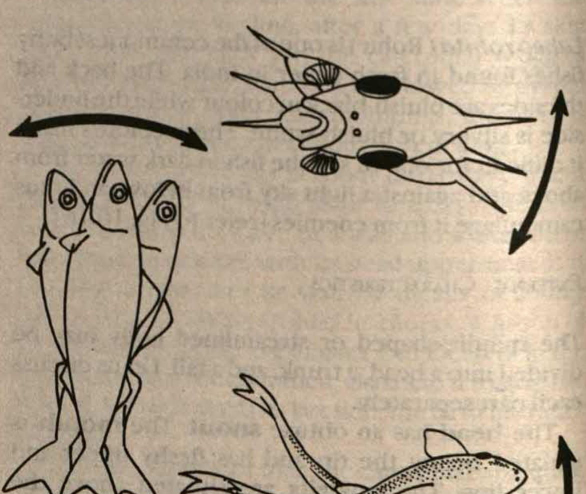


FIG. 10.33 Movements controlled by fins

The paired fins—pectoral and pelvic—control the pitch of the fish. They also enable the fish to swim upwards or downwards, depending upon the

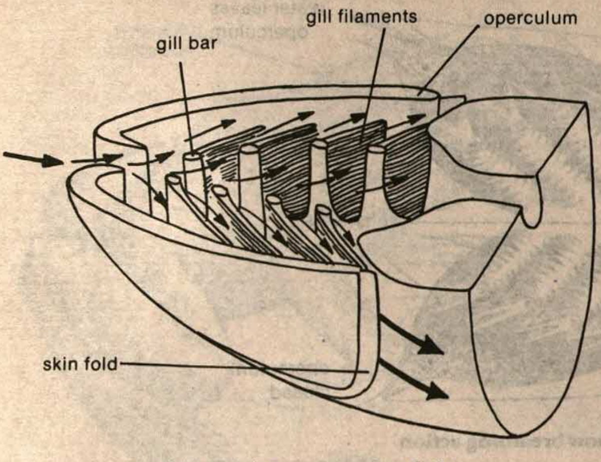


FIG. 10.34 **Breathing in a fish**

angle at which they are held against the body. They keep the fish stable while remaining still in water and also function as brakes due to which the fish slows down and finally stops.

Some fishes have an air-filled sac called **air bladder** or **swim bladder** in their body cavity. This bladder acts like a float and enables the fish to rise up or sink down or remain stationary and stable in water by changing the pressure of air in it. In some lung fishes living in swamps, where water has less oxygen, this bladder is used for breathing air.

BREATHING

The fish breathes with the help of **gills**. There are usually four gills on each side of the **pharynx**. These gills are covered by a bony flap called operculum and are not visible externally [Fig. 10.34]. On each side, between the operculum and the gills, lies a spacious branchial chamber. A regular current of water entering through the mouth and leaving through the opening between the operculum and the body wall is maintained by the coordinated movements of the mouth and the operculum.

Each gill consists of a curved bony gill bar which bears a double row of gill filaments and a row of gill rakers [Fig. 10.35]. The gill filaments project backward, towards the tail and the gill rakers project forward towards the mouth. The gill filaments are thin-walled, branched, and carry an enormous network of blood capillaries within them. They present a very large surface area which comes in contact with water. The water enters the mouth and passes through the mouth cavity, pharynx, gill slits, and branchial chamber and leaves through the opening between the operculum and the body wall. While passing through the gill slits into the branchial chamber, the water flows over the gill filaments. Oxygen dissolved in this water diffuses into the blood in the blood capillaries in the gill filaments and carbon dioxide in the blood diffuses into the water. [see Fig. 10.36.]

The gill rakers act as a strainer and serve to trap the food particles in the water flowing over the gills.

REPRODUCTION AND LIFE HISTORY

Rohu, like other fishes, is unisexual; that is, a particular fish of this species is either male or female. Rohu breeds in rivers during the monsoon (July to

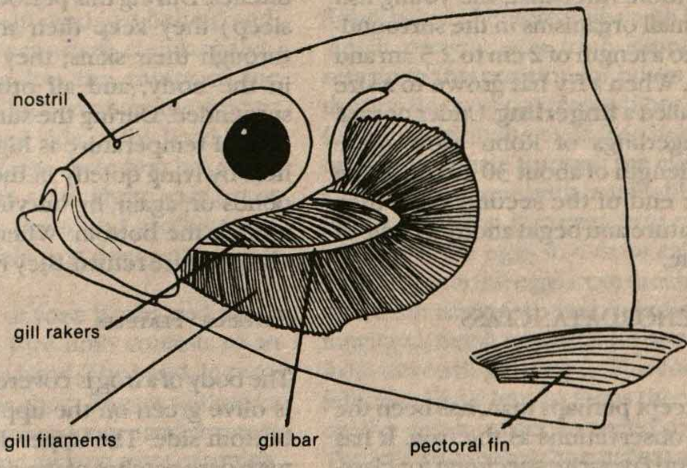


FIG. 10.35 **Side view of a head of a fish showing a gill (operculum removed)**

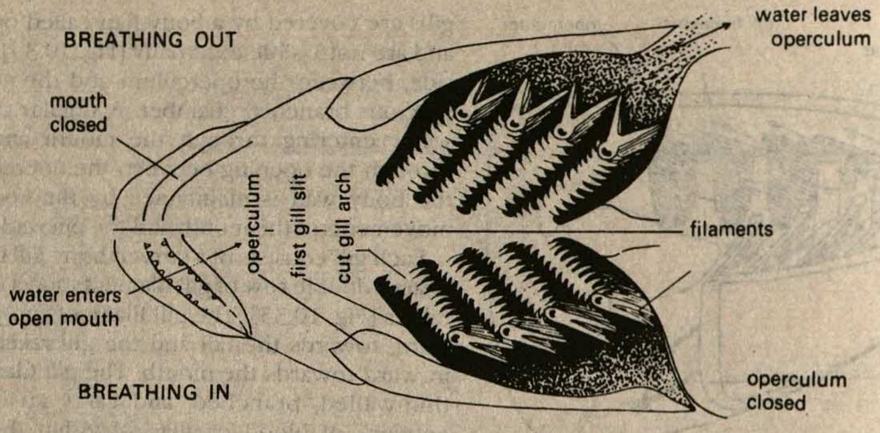


FIG. 10.36 **Diagram to show breathing action**

September). The female fish lays small translucent unfertilised eggs in large numbers. For example, a cod lays five to six million eggs per season. Mating occurs when the male fish passes its **spermatic fluid** or **milt** over the eggs while they are being laid. The milt is secreted through the urogenital opening of the male and fertilises the egges immediately after they have been laid. The fertilised eggs sink to the bottom of the water; most of them are destroyed by other animals, but a few are able to develop. The time required for development depends on the temperature of the surrounding water. The eggs of Rohu hatch over a period of 2 to 15 hours. The **hatchlings** are about 5 mm long, each having a prominent **yolk sac** (containing reserve food) attached on the lower side. For about one week **yolk** from the yolk sac provides the hatchling with nutrition. After that, the young fish begins feeding on small organisms in the surrounding water. It grows to a length of 2 cm to 2.5 cm and is often called a **fry**. When a fry has grown to a size of about 5 cm, it is called a **fingerling**. Under normal conditions, the fingerlings of Rohu grow quite rapidly and attain a length of about 30 cm to 40 cm in one year. At the end of the second year, they become sexually mature and begin another cycle of reproduction and life.

FROG (PHYLUM CHORDATA, CLASS AMPHIBIA)

No other animal, except perhaps man, has been the subject of so many observations as the frog. It has been a convenient and favourite specimen for classroom study for a long time.

Rana tigrina is a widely distributed species of frog in India. Frogs of this species are found commonly in or near water (e.g., in ponds, tanks, ditches, and drains). Water is essential because the frog breathes through its skin, which has to be moist for respiration to occur. Moreover, since the young ones of frogs lead an aquatic life initially, the eggs must be laid in water in order to hatch. The larva feeds only on water weeds, but the adult frog is strictly **carnivorous** and feeds only on insects. The frog is **poikilothermous** (cold blooded), since its body temperature changes with any variation in the temperature of the environment. In other words, its body temperature is low when it is cold outside and high when it is warm outside. Since frogs cannot bear low temperatures, during winter, they bury themselves deep in the mud present in ponds and ditches. During this period of **hibernation** (winter sleep) they keep their mouths shut and breathe through their skins; they live on the food stored in the body, and all other bodily activities are suspended. During the summer, when the environmental temperature is high, frogs escape from the heat by lying quietly in the cool water of pools and ponds or, again, by burying themselves in the wet mud at the bottom. When conditions of optimum temperature return, they resume their normal lives.

EXTERNAL FEATURES

The body of a frog is covered by a slippery skin which is olive green on the upper side and white on the bottom side. The upper side is irregularly spotted with dark patches of varying sizes. The colour of the skin does not remain constant. The body consists of

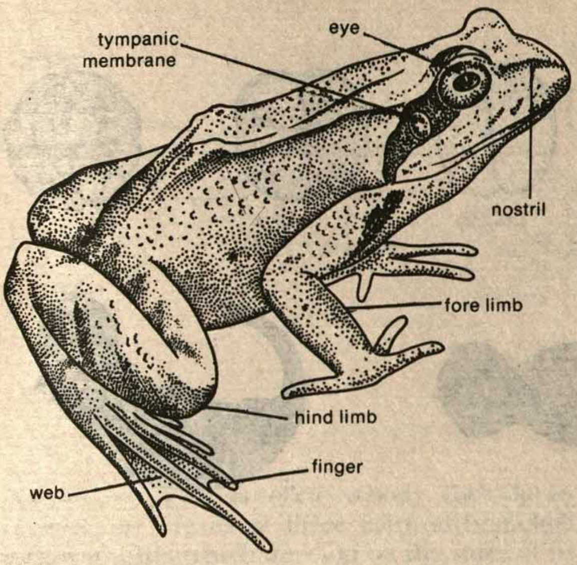


FIG. 10.37 External features of a frog

a conical head and a flattened trunk; there is no neck connecting the head to the trunk [Fig. 10.37].

The **head** has a wide, slit-like **mouth** which enables the frog to freely move its tongue in order to capture insects for food. Just above the tip of the conical head are a pair of **nostrils** which lead into the nasal chambers opening into the mouth cavity by means of **nares**. Above the nostrils are a pair of bulging **eyes** with rounded pupils which help the frog see in nearly all directions. Apart from **upper** and **lower eyelids**, each eye has a third lid called the **nictitating membrane** which is transparent and can be stretched across the pupil for protection. The frog has no **external ear**; however, the **tympanic membrane** is situated just behind and below each eye and appears as a dark, circular patch. The tympanic membrane has the cavity of the **middle ear** just below, which enables the frog to detect sounds. On the lower side of the head, near its junction with the trunk, the male frog has a pair of **vocal sacs**, one on each side. These sacs act as resonators which magnify the sound produced by the **vocal cords**. The female frog does not possess vocal sacs.

The **trunk** bears a pair of **fore limbs** and also a pair of **hind limbs**. Each fore limb consists of an upper arm, a forearm, and a hand. The hand, in turn, consists of a palm and four short fingers without a thumb. The hind limbs are much longer and stronger than the fore limbs. Each hind limb consists of a thigh, a shank, and a foot; the foot has an elongated ankle and five fingers united by a thin, transparent web. The webbed feet enable the frog to swim.

At the rear end of the trunk is located a small opening called the **cloacal aperture**. Faeces (bodily discharges), urine, and genital products (spermatic fluid of eggs) are expelled from the body through this small opening.

LOCOMOTION

In the frog locomotion is effected by leaping (on land) or swimming (in water), for which the powerful hind limbs are admirably adapted. In both forms of locomotion, the hind limbs are bent into the form of a 'Z' and quickly straightened. This action propels the body upwards (while leaping on land) or forward (while swimming in water). In leaping, the fore limbs are used to absorb the shock of falling to the ground again, and, in swimming, they are used to control body balance and to maintain direction.

REPRODUCTION AND LIFE HISTORY

The sexes are distinct in the frog; that is, it is unisexual. In the male frog, two **testes** produce the male sex cells called **spermatozoa**; in the female frog, two **ovaries** produce the female sex cells called **eggs** or **ova**.

Eggs

During the breeding season male and female frogs come in pairs to shallow waters. The first finger of each hand of the male frog develops a large black swelling called a **copulatory pad**. The male frog sits on the back of the female and holds the latter firmly behind her fore limbs with his copulatory pads which prevent him from slipping. The pair may remain in this position for hours or even days, until the female lays eggs through her **cloacal aperture**. In this position the male frog helps to squeeze eggs out of the female through the cloacal aperture. The eggs are covered with a jelly-like material, which swells up when it comes into contact with water and binds the eggs in a mass called a **spawn**. This jelly protects the eggs from mechanical damage and also from drying up and infection by bacteria and fungi and, being unpalatable, prevents other animals from devouring the eggs. The convex surface of the jelly acts like a lens to focus the warmth of sunlight on the egg in order to speed up its development. The jelly also makes the egg float and come in contact with light and air. Small green algae may also get

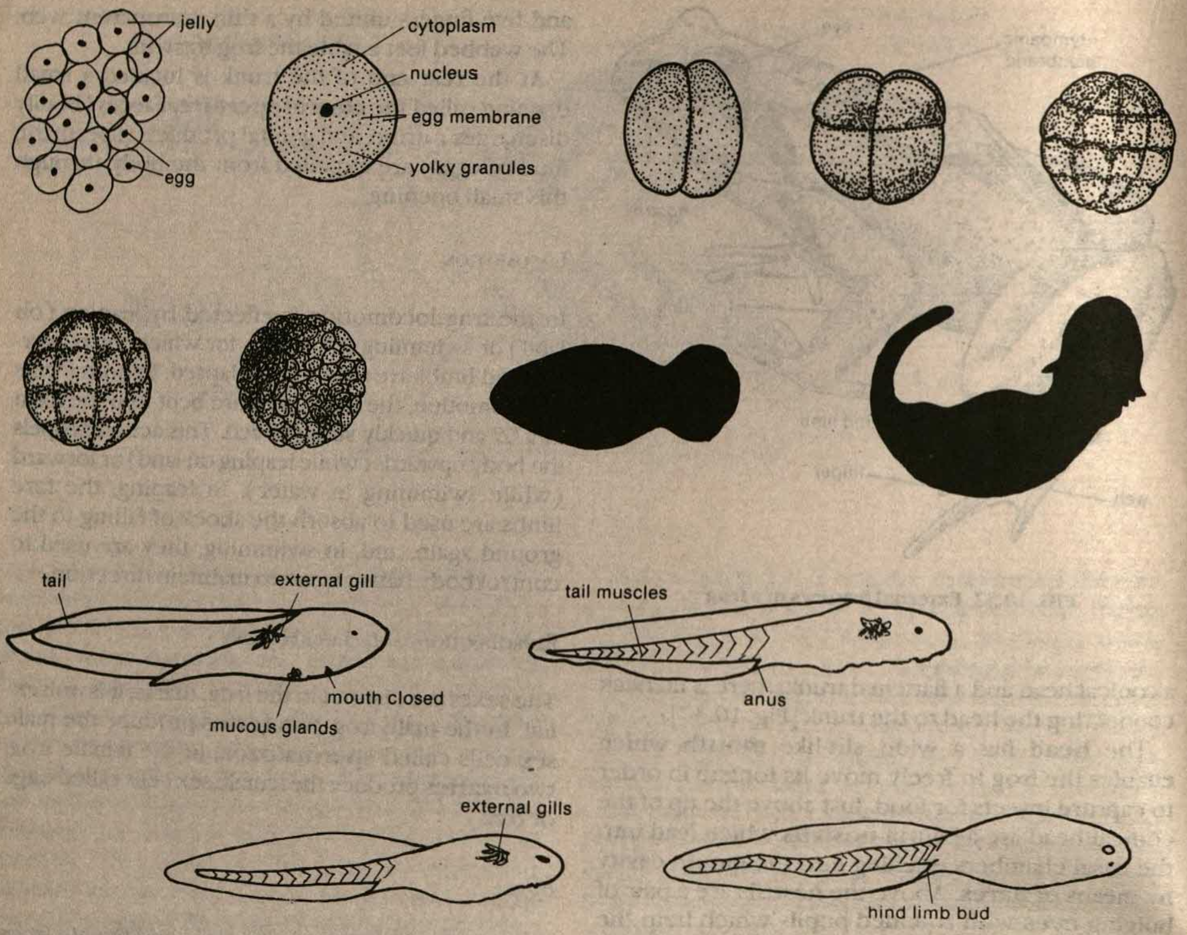


FIG. 10.38 Stages in the development of the embryo of a frog

trapped between the eggs and these supply oxygen to the developing eggs and remove carbon dioxide produced within them.

Immediately after the female lays the unfertilised eggs, the male frog ejects his spermatozoa on them; the sperms penetrate and fertilise the eggs before the outer jelly has time to swell up. Thus, fertilisation is **external**. Each egg is fertilised by a single sperm only; an outer membrane which covers the egg prevents the entry of any more sperms. A fertilised egg is known as a **zygote.** A zygote consists of a small mass of cytoplasm with a nucleus and is enclosed in a membrane. The lower region of the cytoplasm contains yolk. Within 2 to 3 hours after fertilisation, the zygote begins to develop further by means of repeated cell divisions. This leads to the formation of a ball consisting of a large number of cells which later on give rise to different structures. The yolk serves as the source of the food supply needed for the formation of new cells. About four days after fertilisation, a 4-mm long embryo is formed, with a distinct head, trunk, and tail [Fig. 10.38].

Larva

The embryo keeps on developing within the protective jelly and membranes for about two weeks, and then emerges to swim about freely in water. This process of breaking out of the jelly is called **hatching**, and the newly hatched **larva** is called a **tadpole**. The tadpole is a fish-like creature about 7 mm long and has a prominent head, and has no mouth or limbs. Tadpoles swim about freely or attach themselves in clusters to water weeds by means of a secretion from the **cement** or **mucous gland**. At this stage it cannot feed itself and still depends on

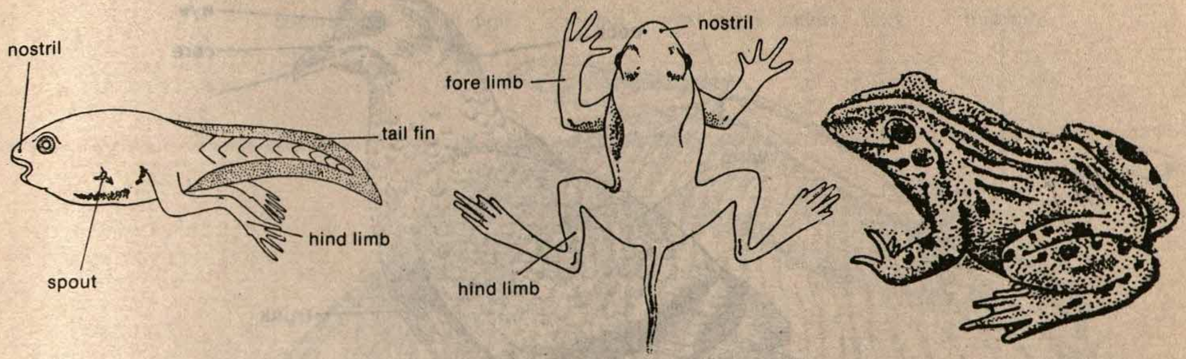


FIG. 10.39 Metamorphosis in a frog

reserve food stored as yolk in its body. The tadpole breathes by means of three pairs of branched **external gills** which develop on the sides of its head [Fig. 10.38]. The skin of the tadpole also helps in breathing. The oxygen produced by water weeds during photosynthesis proves very useful to the tadpoles.

About seven days after hatching, a mouth is formed and the tadpole begins to feed on water weeds. At this stage, new organs begin developing in its body. A long, spirally coiled intestine becomes visible through its transparent skin. Since the tadpole is herbivorous, the alimentary canal is very long. Four gill slits also appear on each side just behind the head. Highly vascular gill filaments develop on the walls of the gill slits. A fold of skin appears on either side, just in front of the first gill slit. This is known as the **operculum**. These folds of skin grow backward, and just behind the last gill slit, these folds become fused with the body wall except for a small opening called **spiracle** or **spout** on the left side. Thus, the gill slits and the internal gills become fully enclosed within the operculum. The external gills gradually shrivel up and disappear. The tadpole uses the internal gills for breathing just like a fish. At this time, other structures such as the liver, pancreas, kidneys, and lungs, are also formed. The fore limbs and hind limbs also appear as small buds which will gradually develop into proper limbs. The tail of the tadpole is muscular and has vertically flattened dorsal and ventral fins which help it in swimming. The tadpole is now fully developed, but, even at this stage, it is quite unlike the young frog.

Metamorphosis

At this point of time, the tadpole undergoes a series of remarkable changes which transform it from the fish-like, herbivorous animal to a tailless carnivorous adult frog. The process by which the larva changes its structure and functions to become the adult frog is called **metamorphosis**. This process occurs as follows [Fig. 10.39]. The tadpole stops feeding and becomes much less active; its tail begins to shrink and its gills stop functioning as lungs develop within its trunk. The gills finally disappear and the animal begins breathing in air directly from the atmosphere into its lungs. The long, spirally coiled alimentary canal of the tadpole becomes shorter and the young animal gradually becomes **carnivorous**, feeding on small insects instead of water weeds. The blackish skin turns light green.

The tail shrinks to a small stump and disappears completely. At this stage, the animal moves from water to land; it is now a small baby frog.

The entire process of development from the fertilisation of the egg to the appearance of a small frog takes three months. This period may vary slightly according to environmental conditions, especially the temperature of the water.

PIGEON (PHYLUM CHORDATA, CLASS AVES)

Pigeons have always been fancied by human beings for their appearance and have also been used as 'message carriers' for a very long period. Many varieties of pigeon have been produced by artificial breeding.

The Indian blue rock pigeon, *Columba livia*, is found virtually throughout the country. In the countryside, it builds its nest on cliffs, among rocks, and in cities and towns on edges of buildings and other structures. It feeds principally on grains, but also eats fruits, shoots, and buds. Sometimes, it feeds

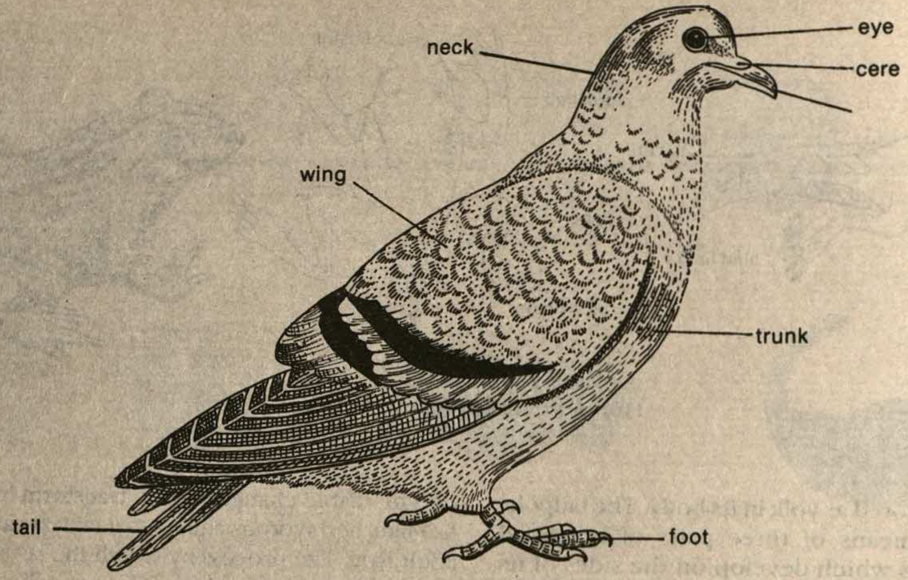


FIG. 10.40 *Columba livia*: The common Indian blue rock pigeon

even on small snails. During the day, the pigeon performs several activities, such as feeding, flying and breeding. At night it rests in its nest.

EXTERNAL FEATURES

The body of the *Columba livia* is divided into a more or less rounded head, a highly mobile neck, a massive trunk (from which two powerful wings and two short legs arise), and a short tail. The entire body, except the legs, is covered with a **plumage** of feathers. The plumage is bluish-grey with glistening metallic green and purple (or magenta) on the upper breast and around the neck. All the feathers overlap each other and are directed backwards, so that the body offers minimum resistance to air during flight [Fig. 10.40].

The **head** is elongated and has a rounded **cranium** in which the brain is situated. In front the head bears a prominent **beak**. On either side of the beak, at the base of its upper portion, is a patch of naked, swollen skin called the **cere**. At the base of each cere is a **nostril** through which breathing takes place. The head also bears a pair of large eyes, each with an upper and a lower eyelid and a transparent **nictitating membrane** (which forms a third eyelid, as in the frog). A circular opening called the **auditory aperture**, which is used for hearing, is located a little behind and a little below each eye.

The **trunk** is separated from the head by a short neck. The neck is highly mobile. The trunk and the neck are covered with feathers, which form an insulating layer around the body of the bird and help in keeping its body temperature constant. The trunk bears the wings and the legs of the bird. The wings are, in fact, modified **fore limbs** that are heavily covered with feathers called **remiges** (singular **remex**) or **flight feathers**. When the bird is at rest, the wings are folded back against the trunk in the form of a 'Z'. Each wing has the following features characteristic of a fore limb [Fig. 10.41]:

(1) an 'upper arm' without remiges;
(2) a 'forearm' with 12 remiges, called **primaries**; and
(3) a 'hand' which consists of a wrist, a palm, and three digits. The first digit bears a tuft of small feathers called the **bastard wing**. There are further 11 remiges, called **secondaries**, on the hand.

The two legs on which the pigeon rests and walks are, in fact, the **hind limbs**. Each hind limb consists of a short thigh, a long shank, and a foot with an elongated ankle and four clawed digits. Three of these digits point forward, while the fourth points backward. Both hind limbs are largely covered with feathers, leaving only a part of the shanks and the feet exposed. These featherless parts of the shank and the feet are covered with scales.

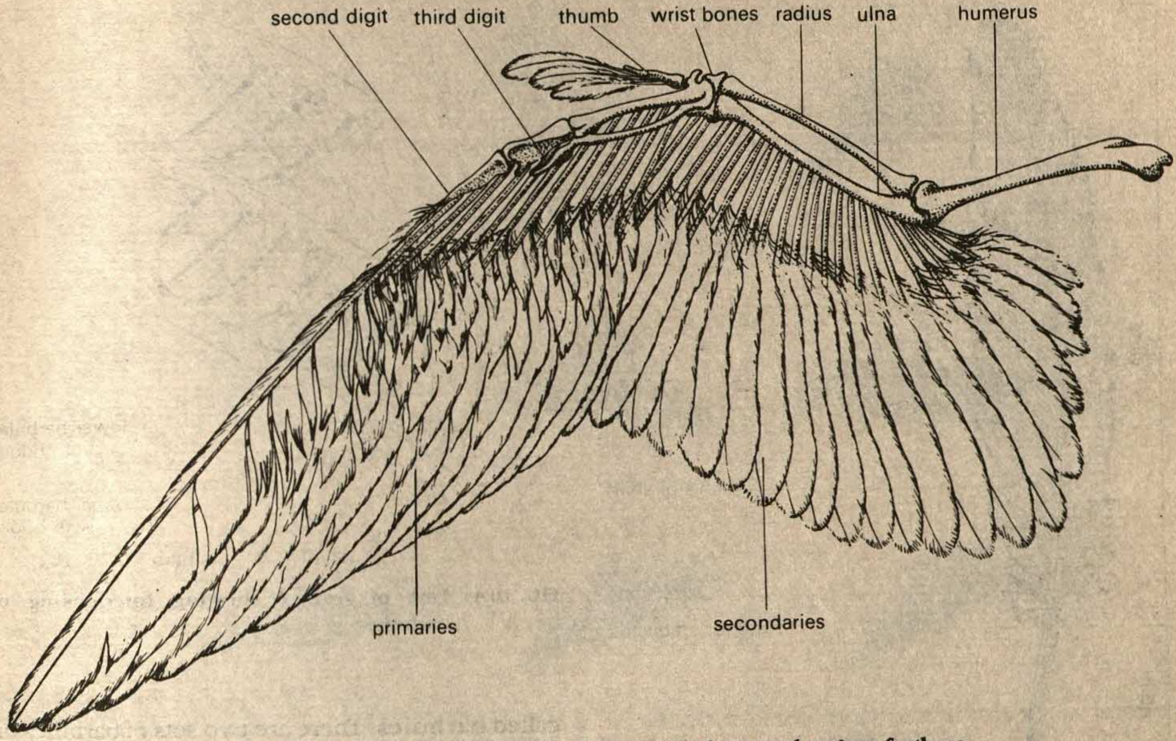


FIG. 10.41 **Structure of birds' wing, showing skeleton and various feathers**

The **tail** is short and is located at the end of the massive trunk. At its base, on the underside, is located a transverse **cloacal aperture** which serves as a common outlet for faeces, urine, and genital products. On the upper side of the tail is a short **papilla**, at the tip of which is the opening of an oil gland.

FEATHERS

Feathers develop on different parts of the body of the bird and are different in their structure, function, and appearance. They are named as follows [Fig. 10.42]:

(1) **Quill feathers** are large in size and are found on the wings and the tail. Those on the wings are called **remiges**, while those on the tail are called **rectrices** [Fig. 10.43].

(2) Contour feathers or **coverts** are the feathers which cover the body of the bird and are smaller than quill feathers.

(3) **Filoplumes** are delicate, hair-like feathers found amongst the contour feathers on the body.

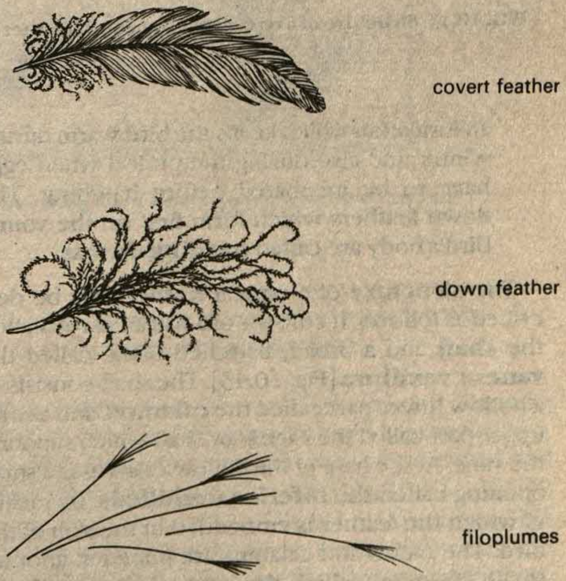


FIG. 10.42 **Different types of feathers covering the body of a bird**

(4) **Down feathers are short and woolly feathers which also cover the entire body. They form**

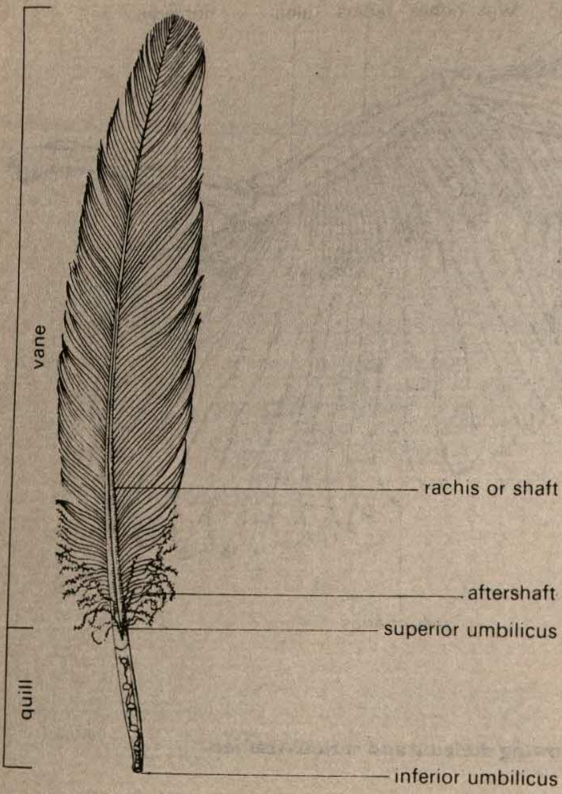


FIG. 10.43 Structure of a typical feather (quill feather)

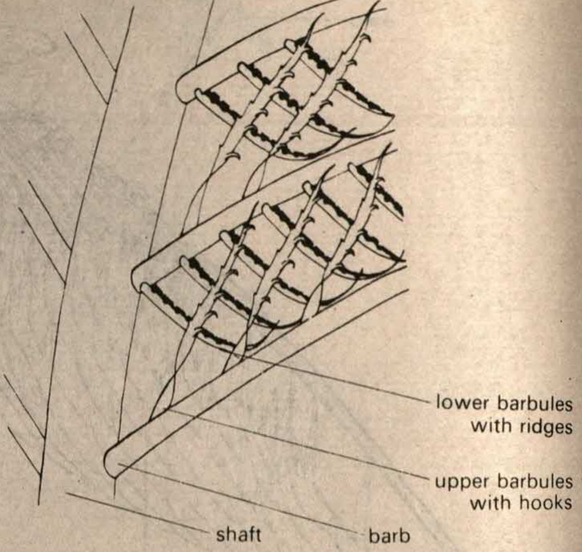


FIG. 10.44 Part of feather showing interlocking of barbules

an insulation which keeps the bird warm during winter and also during the period when eggs have to be incubated before hatching. The down feathers which form first on the young bird's body are called **nestling downs**.

The **structure** of a typical feather may be described as follows. It consists of a stiff axial rod called the **shaft** and a broad, flattened blade called the **vane** or **vexillum** [Fig. 10.43]. The shaft consists of a hollow lower part called the **calamus**, and a solid upper part called the **rachis** or shaft which supports the vane. At the base of the hollow calamus is a small opening called the **inferior umbilicus**, by means of which the feather is embedded in the skin of the bird. The rachis and calamus are joined at another small opening called the **superior umbilicus** which is located on the underside of the rachis or shaft. The superior umbilicus is generally covered with a tuft of small feathers called the **aftershaft**.

The vane consists of a large number of hair-like branches called **barbs** arranged obliquely on either side of the rachis. The barbs bear further branches called **barbules**. There are two sets of barbules on each barb: the barbules which face the base of the feather are called **lower** or **proximal barbules**, while those which face the tip of the feather are called **upper** or **distal barbules** [Fig. 10.44]. Small hooklets on the distal barbules interlock with the corresponding ridges on the proximal barbules. Such an interlocking system of adjacent barbules provides an unbroken surface and also flexibility to the vane. Whenever the hooklets become unfastened accidentally and the surface of the vane broken, the bird **preens** (combs) the barbs with its beak and sets the barbules in their correct positions, thus smoothening out the feather again.

FLIGHT IN BIRDS

Birds are very suitably built for flight. The more prominent features of their structure which help them to fly are:

(1) Wings have a large surface area provided by feathers.

(2) Large and powerful muscles for flight, called the **pectoral** muscles (situated around the breast).

(3) A strong bony projection of the **sternum** (breastbone) called the **keel** to which the pectoral muscles are attached.

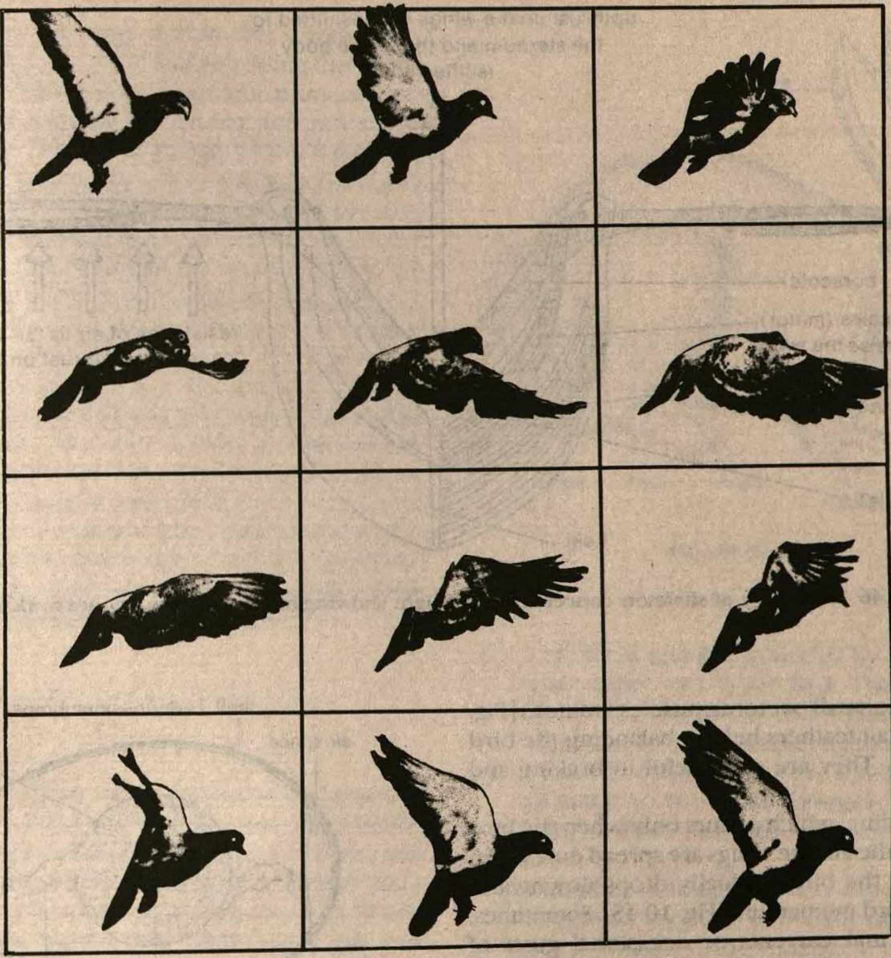


FIG. 10.45 Series of twelve photographs showing the wing movement of pigeon during flapping

(4) A streamlined body, which offers minimum resistance to air.

(5) A powerful tail which acts as a rudder as well as a brake. It also balances the body during flight.

(6) A very strong sense of sight. The eyes are shaped and located in such a manner on the head that the birds can see in all directions at the same time.

(7) A very well-developed brain.

(8) A very light body. The structures in a bird's body which help in making it lighter and, hence, more suitable for flight are:
   (a) air-filled air sacs. The air sacs are outgrowths from the lungs;
   (b) absence of teeth;
   (c) hollow and spongy (air-filled) bones;
   (d) absence of one ovary in the females;
   (e) extremely light feathers.

Birds exhibit two types of flight, namely, flapping [Fig. 10.45] and gliding (or soaring). During flapping, the big pectoral muscles (major) contract and pull the wings downwards. Now, resistance of air to the wings leads to an upward thrust on the wings. This force is transmitted to the sternum and causes the whole body to be lifted up. The forward momentum is also provided by the wings—especially by the parts of the wings near their tips. During the downstroke of the wings, the forward edges of the wings are always below the backward edges, so that when the wings push the air backwards, the air pushes the bird forward. The wings are raised up by the con-

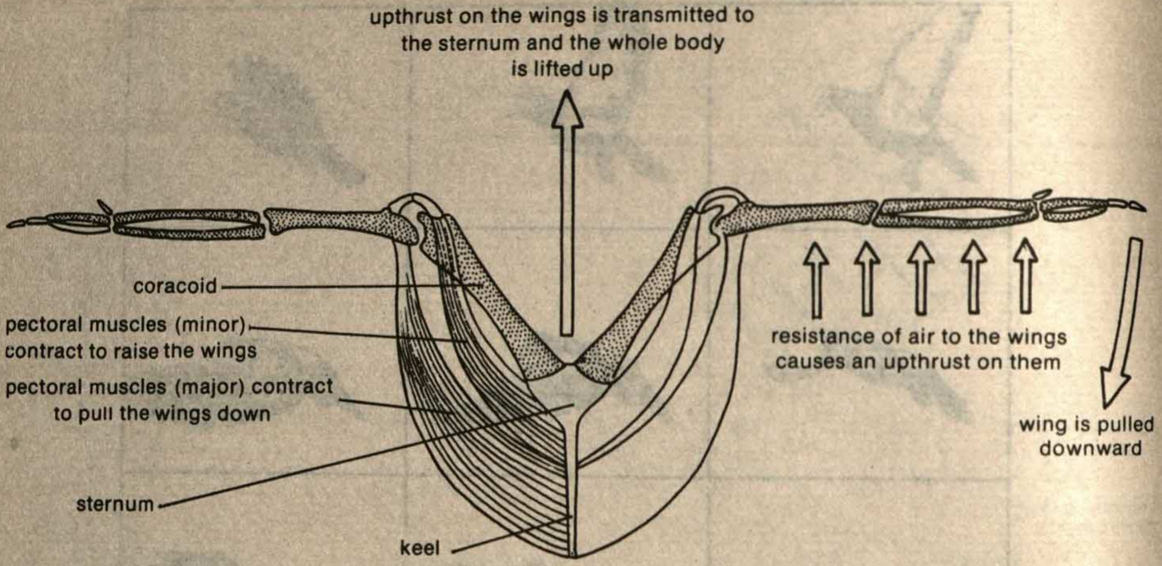

upthrust on the wings is transmitted to the sternum and the whole body is lifted up
coracoid
pectoral muscles (minor) contract to raise the wings
pectoral muscles (major) contract to pull the wings down
sternum
keel
resistance of air to the wings causes an upthrust on them
wing is pulled downward

FIG. 10.46 Front view of skeleton concerned with flight showing how muscles and bones work together

traction of the small pectoral muscles (minor) [Fig. 10.46]. The tail feathers help in balancing the bird during flight. They are also useful in braking and landing.

During gliding, which occurs only when the bird is high up in the air, the wings are spread out. When this happens the bird gradually drops downward, gaining forward momentum [Fig. 10.45]. Sometimes, upward thermal currents or occasional gusts of wind are also used by birds to gain height without resorting to wing movement.

Reproduction and Life History

In birds the pattern of reproduction consists of pairing, nest building, mating, egg laying, incubation and development, followed by parental care. Among pigeons, the sexes are separate, although, in appearance, the male and the female are alike, both having a pair of dark bars on their wings. While mating, the male mounts the female, applies his cloacal aperture to that of the female, and introduces **sperms** into her **oviducts**. This is the process of **internal fertilisation** of the eggs in the ovaries of the female. The eggs which she lays are **fertilised**.

Each egg is enclosed within a mass of **albumen** and also an outer shell as it travels down along the oviduct from the ovary to the cloacal opening. The shell is hard, calcareous (containing calcite), and porous and is internally lined with two membranes [Fig. 10.47]. These membranes enclose the mass of albumen. At the broad end of the egg is an air space between the two shell membranes. Albumen or the white of the egg is very rich in proteins and is also a source of water. The yolk is suspended between two twisted threads of albumen. On one side of the yolk lies the **germinal disc**, which contains the female sex cell. After fertilisation, the fertilised egg cell develops into an embryo. The yolk and the germinal disc together constitute the ovum or the egg cell.

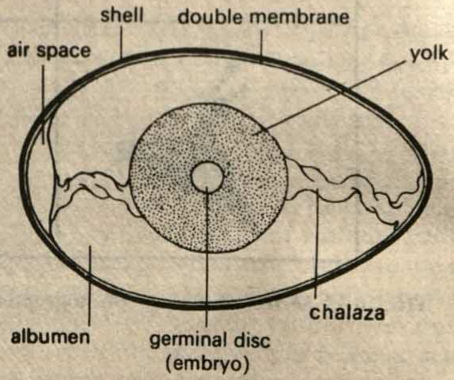


FIG. 10.47 Structure of bird's egg before hatching

A temperature of 38°C to 40°C is needed for the growth and development of the **embryo**. The female bird maintains the eggs within this temperature range by sitting over them and providing them with her body heat. This is known as incubation and lasts for 14 days among pigeons. During this period, the fertilised female sex cell in an egg divides repeatedly and the tissues and organs of a young pigeon develop within the shell. The yolk serves as a source of food and the albumen as a source of both food and water during incubation. Respiration occurs by the diffusion of oxygen and carbon dioxide, respectively, into and out of the egg through the porous shell and the semipermeable membranes. At the end of the incubation period, a chick is fully formed. It either breaks out of the shell by using its beak or is naturally hatched out of it. The newly hatched chick is blind, and is either covered with a few feathers or has no feathers at all. The parents look after the young ones and feed them for a week or two. During this period the offspring grow and develop feathers. After that, they climb out of the nest and begin to fly. Soon after, they start leading independent lives.

RABBIT (PHYLUM CHORDATA, CLASS MAMMALIA)

The rabbit is a clean, timid and harmless mammal which lives in burrows in fields and feeds herbivorously. It spends the day resting in a burrow, and emerges to feed or play at dawn or at dusk. It has a number of natural enemies (such as cats, dogs, foxes, wolves, jackals, hawks, and eagles) and can run quite fast (at a speed of 30 kmph to 35 kmph) in case of danger. It protects itself by hiding in burrows.

EXTERNAL FEATURES

The entire body of the rabbit is covered with a fur of soft hair. This fur helps it to maintain a constant body temperature. The colour of the fur may vary: it may be white or brown or grey or black, and such variation provides camouflage for the rabbit in its natural environment. The body is divided into four distinct portions: head, neck, trunk, and tail [Fig. 10.48].

The **head** is a complex structure. It consists of the following parts:

(1) A pair of prominent eyes. Each eye has a lower lid and an upper lid, and also a nictitating membrane in the inner corner.

(2) A pair of long, trumpet-shaped, mobile **outer ears (pinnae)** towards the top of the head. They serve to direct sound vibrations to the external and middle ear.

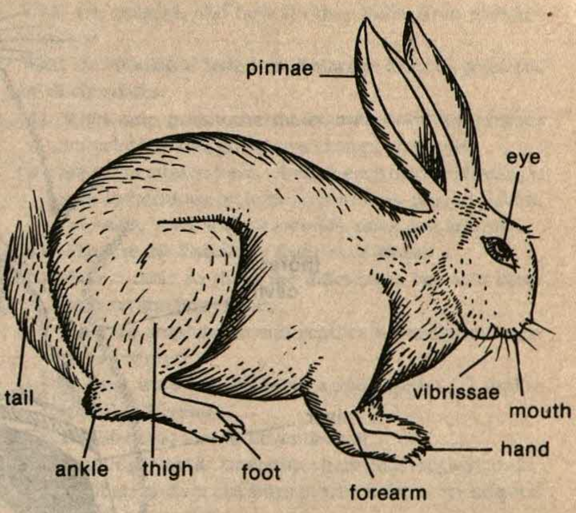


FIG. 10.48 Rabbit

(3) A terminal **mouth**, bounded by mobile, muscular upper and lower **lips**. The upper lip is cleft in the middle to form a **hare lip**, due to which the **incisor (front)** teeth are visible.

(4) A pair of nostrils, which are small and oblique openings to the nasal passages. The sensory cells in these passages serve as receptors of smell.

(5) A number of long, stiff hairs called **vibrissae**, located on the sides of the **snout**. Commonly called 'whiskers', the vibrissae are sensitive to touch and enable the rabbit to judge whether it can pass through a burrow or not.

The **neck** is short and flexible and connects the head to the trunk. It also supports the head and controls its movements.

The **trunk** is divisible into two parts, namely, the **thoracic** (chest) cavity and the **abdominal** (belly) cavity. The former mainly accommodates the heart and the respiratory organs, while the latter contains almost the entire alimentary canal. The trunk bears two pairs of limbs: the **fore limbs** located towards the anterior (front) end of the trunk and the **hind limbs** located towards the rear end. The fore limbs are short and stout. They enable the rabbit to burrow and to absorb the shock of landing on hard ground at the end of a leap. Each fore limb has an upper arm, a forearm, a wrist, a palm, and five clawed digits or fingers. The hind limbs are longer and more muscular, providing the power for running or leaping. Each hind limb consists of a long thigh, a

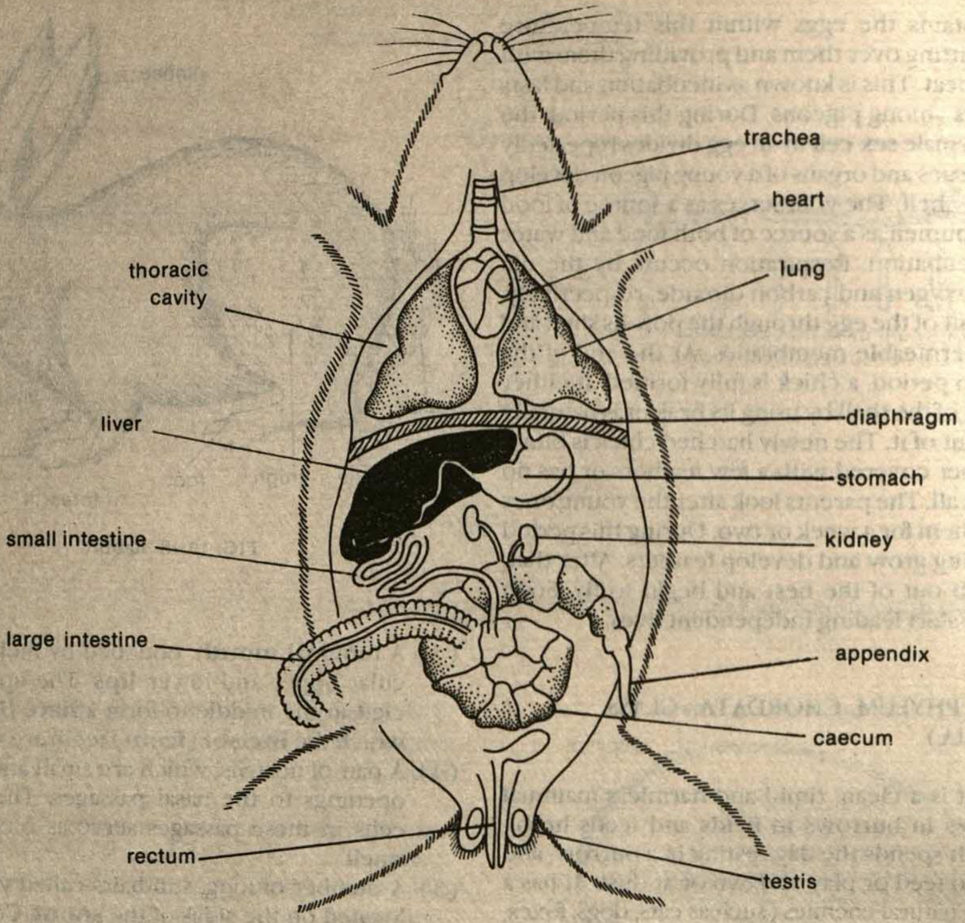


FIG. 10.49 Alimentary canal of rabbit

shank, an ankle, and a foot with an instep and four clawed toes.

The **anus** lies at the rear end of the trunk, just below the tail. The **urogenital opening** lies in front of the anus, on the lower side of the trunk. In the female rabbit, the milk glands which produce food for the young ones open out into four or five pairs of teats on the underside of the trunk.

The **tail** is short, bushy, and upturned. It is used to transmit signals to other rabbits when they gather in a group. On being alarmed, a rabbit flicks its tail and the entire group immediately runs to take shelter.

INTERNAL ARRANGEMENT OF ORGANS

Beneath the hairy skin of the rabbit lies a layer of **muscles**. The skin and the muscles are attached by connective tissue. Together, they constitute the **body wall**. Embedded in the layer of muscles is the **skeleton** (framework of bones).

The body wall encloses a spacious body cavity called the **coelom**. The coelom is divided into two by a transverse muscular partition called the **diaphragm**; the smaller, anterior division is called the **thoracic cavity** and the larger posterior division the **abdominal cavity**. When the rabbit is in a position of rest, the diaphragm bulges forward into the thoracic cavity. [See Fig. 10.49.]

The **thorax** (thoracic cavity) contains the **heart** and the **lungs**, both organs being protected by the ribs. It also contains the **trachea** (windpipe), the **blood vessels**, which enter and leave the heart and the lungs, and the **food pipe**, which leads to the stomach in the abdominal cavity.

The **abdomen** (abdominal cavity) contains almost the entire **alimentary canal** (stomach, duodenum, ileum, vermiform appendix, caecum, colon, and rectum). It also contains the pancreas, the liver, the kidneys, the testes or ovaries and associated organs, i.e., ureter, urinary bladder, and various blood vessels to and from the heart [Fig. 10.49]. All these organs are well enclosed and well protected within the body wall. Finally, Table 10.4 sums up the major differences between vertebrates and invertebrates.

TABLE 10.4 DIFFERENCES BETWEEN VERTEBRATES AND INVERTEBRATES

VERTEBRATES	INVERTEBRATES
1. **Notochord** (a stiff supporting rod) is placed, at least in early life, in the mid-dorsal line of the body.	**Notochord** is never present.
2. Presence of living **endoskeleton** (e.g., skull, vertebral column).	Absence of endoskeleton; non-living **exoskeleton** may be present.
3. **Appendages** or **limbs** are never more than two pairs.	Appendages, when present, are more than two pairs.
4. The **skin** consists of two layers.	The **skin** consists of one layer.
5. **Eyes** originate from the brain. Compound eyes are absent.	Eyes originate from the skin. Compound eyes are present.
6. **Pharynx** is perforated on either side by a series of **gill slits**.	**Gill slits** are never formed.
7. The **central nervous system** (brain and spinal cord) is a hollow tube placed in the mid-dorsal line of the body.	The **central nervous system** is a solid cord placed in the mid-ventral line.
8. The **heart** is present ventrally and beneath the gut.	The **heart**, when present, is present dorsally and above the gut.

EXERCISES

SECTION 1

1. (a) How do protozoans differ from other animals?
   (b) Name some harmful protozoans and explain how they are harmful to human beings.
2. List all the important characteristics of sponges.
3. Name that phylum most of whose members possess stinging cells. How are these cells used by such animals?
4. (a) How do flatworms differ from roundworms?
   (b) Name five parasitic worms and state how they harm human beings.
5. List all the important characteristics of insects.
6. What are annelids and how do they differ from platyhelminthes?
7. What are chordates? State two distinctive features possessed by all chordates.
8. (a) What are poikilothermous and homoiothermous animals? Explain, giving two examples of each.
   (b) State, in a tabular form, whether each of the following is poikilothermous or homoiothermous: pigeon, rabbit, eel, snake, toad, shark, crocodile, snail, dog, and man.
9. (a) What are the distinctive features of fishes?
   (b) Make a table to show the differences between cartilaginous and bony fishes.
10. (a) Why are amphibians and reptiles normally not seen during winter?
    (b) In what ways are amphibians and reptiles (i) similar and (ii) different?
11. Why do fishes and insects never drown?
12. Make a table giving the similarities between frogs and toads.
13. (a) What are the special ways in which fishes are adapted to living in water?
    (b) What are the special ways in which birds are adapted to flying in air?
14. Make a table showing the different ways in which fishes, birds, and mammals are useful to man.
15. Name the following: (a) one flying mammal; (b) one aquatic mammal; (c) one burrowing mammal; (d) the largest mammal; (e) the smallest mammal; (f) two ant-eating mammals; (g) two omnivorous mammals; (h) three animals with a spiny skin; (i) five animals which can regulate and maintain their body temperature; (j) two chordates with shells; (k) five animals with streamlined bodies; (l) two animals which do not have any glands in their bodies; (m) five animals with scaly skins; (n) two hermaphrodite animals; (o) ten vertebrates which live in water; (p) two animals which cause human diseases; (q) five insects which are useful to human beings; (r) five insects which are harmful to human beings; (s) two animals having small pores in their body walls; and (t) one mammal which lays eggs.
16. (a) Name the two types of mosquitoes, and list the diseases that each type is responsible for spreading.
    (b) How can the two types of mosquitoes be distinguished from each other on the basis of structure and behaviour?
17. Make a table listing the various parts of the body of a mosquito and their respective structures and functions.
18. (a) What are the differences between the larva and the pupa of a *Culex* mosquito?
    (b) Make a chart for the life history of a mosquito indicating the time taken for each stage, the processes that occur during that time, and the characteristics of each stage through which the mosquito passes before attaining adulthood.
19. (a) How do mosquitoes spread?
    (b) What effective measures can be taken to control or eradicate the diseases spread by mosquitoes?
    (c) What do you understand by the term 'the biological control of insects'?
20. (a) What are 'compound eyes' and what advantage do they have over simple eyes? Answer with reference to the

mosquito and butterfly in comparison with man.

(b) Describe the mouth parts of a butterfly and explain how it feeds.

(c) On what do butterflies feed?

21. You must have seen moths in your houses during the evenings and nights. Capture one and study its structure and behaviour. Then refer to an encyclopedia in your school library and make a chart comparing the structure, behaviour, and life history of a moth and a butterfly.

22. (a) Explain the following terms: (i) true legs and pro-legs; (ii) spiracle; (iii) moulting; and (iv) cremaster.

(b) Discuss the structural and behavioural differences between the larva and the pupa of a butterfly.

(c) Before or after summer, you can capture a caterpillar from a garden. Place it in an empty shoebox with a lid, making holes on the sides and top of the box to allow air circulation. Feed the caterpillar on the same type of leaves on which you found it. Observe its behaviour and watch it gradually grow and change into an adult butterfly.

23. (a) How does the cabbage-white butterfly protect itself from its enemies?

(b) In what ways are butterflies dangerous pests?

24. In fishes describe the organs of breathing and the process of breathing.

25. (a) How does the arrangement of scales on the surface of the body of a fish body help it?

(b) How do various fins help the fish?

(c) Draw diagrams to show the methods of swimming used by fishes.

26. How, and with which organs, do fishes detect various stimuli?

27. Why are fishes considered to be a food with a high nutritive value for human beings?

28. (a) What do you understand by the word 'poikilothermous'?

(b) How do frogs react to very hot and very cold weather?

29. (a) Of what advantage to a frog are its wide mouth and long tongue?

(b) What is the function of the nictitating membrane in the frog?

(c) How does the frog hear sounds?

30. How are the limbs of a frog suited for living in water as well as on land?

31. (a) State how a tadpole differs from an adult frog with respect to the following:

(i) Choice of food and feeding habits.

(ii) Breathing organs and mode of breathing.

(iii) Mode of locomotion.

(b) What do you understand by 'metamorphosis'? Describe its occurrence in the life history of a frog.

32. Why do frogs always remain near water?

33. (a) How does streamlining of a bird's body help in flying?

(b) What advantages does a bird gain by possessing feathers?

34. (a) Name the different types of feathers found on the body of a bird.

(b) Draw a simple diagram of, and describe, a typical feather.

(c) What are proximal and distal barbules and what purpose do they serve?

35. (a) Describe the process of flight of a bird.

(b) How is the pigeon suited for flight?

36. (a) What is internal fertilisation?

(b) How does internal fertilisation differ from external fertilisation (which you learnt while studying frogs)?

37. (a) Draw a labelled diagram of a bird's egg to show the following: shell, double membrane, albumen, yolk, ovum, and germinal disc.

(b) What is 'incubation'? Briefly describe the changes which take place in the egg during this process. What is the period of incubation in pigeons?

Part 4: The Biology of Flowering Plants

CHAPTER 11

The Root: Characteristics, Structure, Functions, and Modifications

CHARACTERISTICS OF ROOTS

The **root** is the descending organ of the plant which grows from the radicle of a seed. It grows below the ground, towards moisture and gravity, and away from light. The root does not normally bear buds except in some cases, e.g., sweet potato and Indian redwood, where roots bear vegetative buds and are used for vegetative reproduction. It never bears nodes, internodes, flowers, fruits, and seeds. The roots not only fix the plant in the ground but also absorb water and mineral salts from the soil.

TYPES OF ROOTS

The direct growth of the radicle leads to the formation of the primary root. If it persists and continues to grow, as in **dicotyledonous** plants, the primary root produces lateral branches called **secondary roots** which, in turn, produce more branches called **tertiary roots**. All these roots together form the **tap root system** of the plant. All the lateral branches are produced in **acropetal** succession, that is, the older and longer branches are away from the tip and the younger and shorter ones towards it [Fig. 11.1].

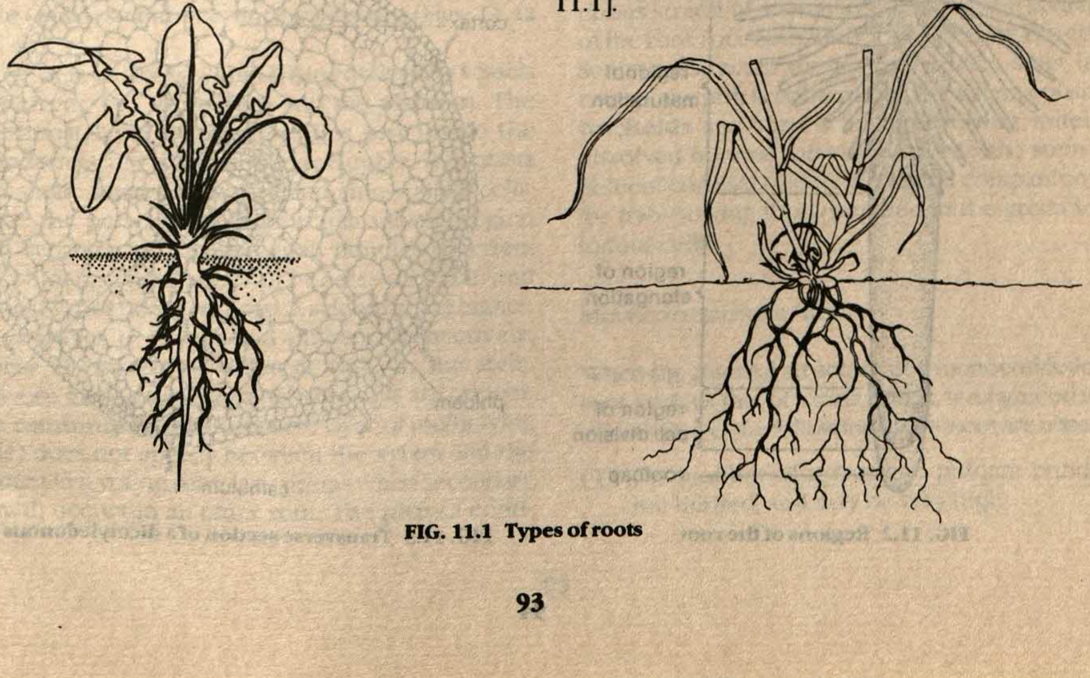


FIG. 11.1 Types of roots

Roots that develop from any part of the plant body other than the radicle are called **adventitious roots**. In **monocotyledonous** plants, the primary root does not persist, and a cluster of slender fibrous roots grows from the base of the stem. Adventitious roots also grow from nodes and even internodes; for example, in grass, sugarcane, and maize, and from stem cuttings. In *Bryophyllum* and *Begonia*, adventitious roots, called foliar roots, grow from the leaves (see functions of leaves).

REGIONS OF THE ROOT

The apex of each root is protected by a **root cap**. Such protection is essential since the apex of a root is delicate and consists of rapidly dividing cells. This is known as the **region of cell division** and extends to a length of a few millimetres. Some of the cells formed in this region form the root cap and the others form the next upper region known as the **region of elongation**. The region of elongation also extends to a length of a few millimetres and the cells of this region undergo rapid enlargement and elongation and lead to a growth in the length of the root. The **region of maturation** lies above the region of elongation and extends upwards. Its basal portion contains a cluster of very fine and delicate thread-like structures called **root hairs**, above which are produced the lateral branches. The cells of this region undergo differentiation and maturation into various plant tissues according to the functions they perform later on [Fig. 11.2].

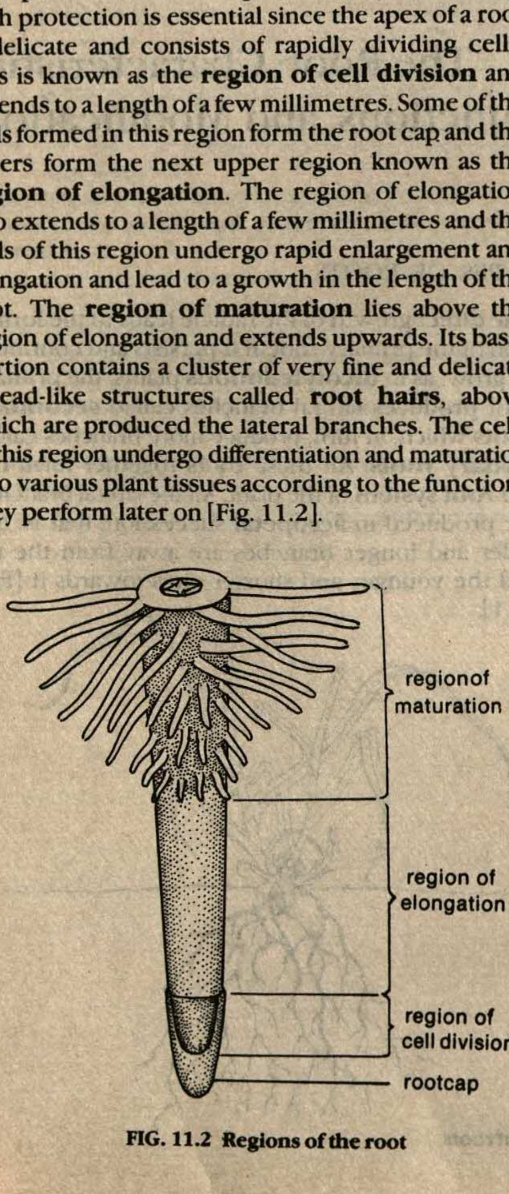


FIG. 11.2 Regions of the root

Root hairs serve to increase the surface area for the absorption of water and inorganic salts from the soil. Root hairs are unicellular.

INTERNAL STRUCTURE OF ROOTS

DICOTYLEDONOUS ROOT

In a very thin slice (transverse section) of a young gram root examined under a microscope, the following internal structures may clearly be seen [Fig. 11.3].

The **epidermis** or **epiblema** is the outermost layer of thin-walled cells; this layer is only one cell thick. In the region of maturation, the outer walls of these epidermal cells extend to form unicellular **root hairs**. Thus, each root hair is a long, slender projection or extension of a single epidermal cell. Root hairs increase the absorbing surface of the root and help the plant absorb water and dissolved mineral salts from the soil.

The **cortex** is a wide region beneath the epidermal layer consisting of several layers of large, thin-walled **parenchyma cells** separated from each other by intercellular spaces. These cells contain leucoplasts and store starch grains. The innermost layer of the cortex is one cell thick and is called the **endodermis**; it consists of barrel-shaped cells tightly packed together. The endodermis surrounds the

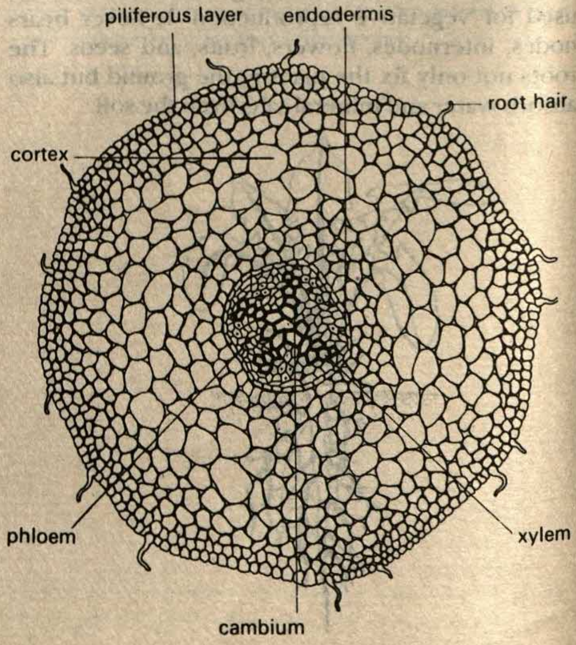
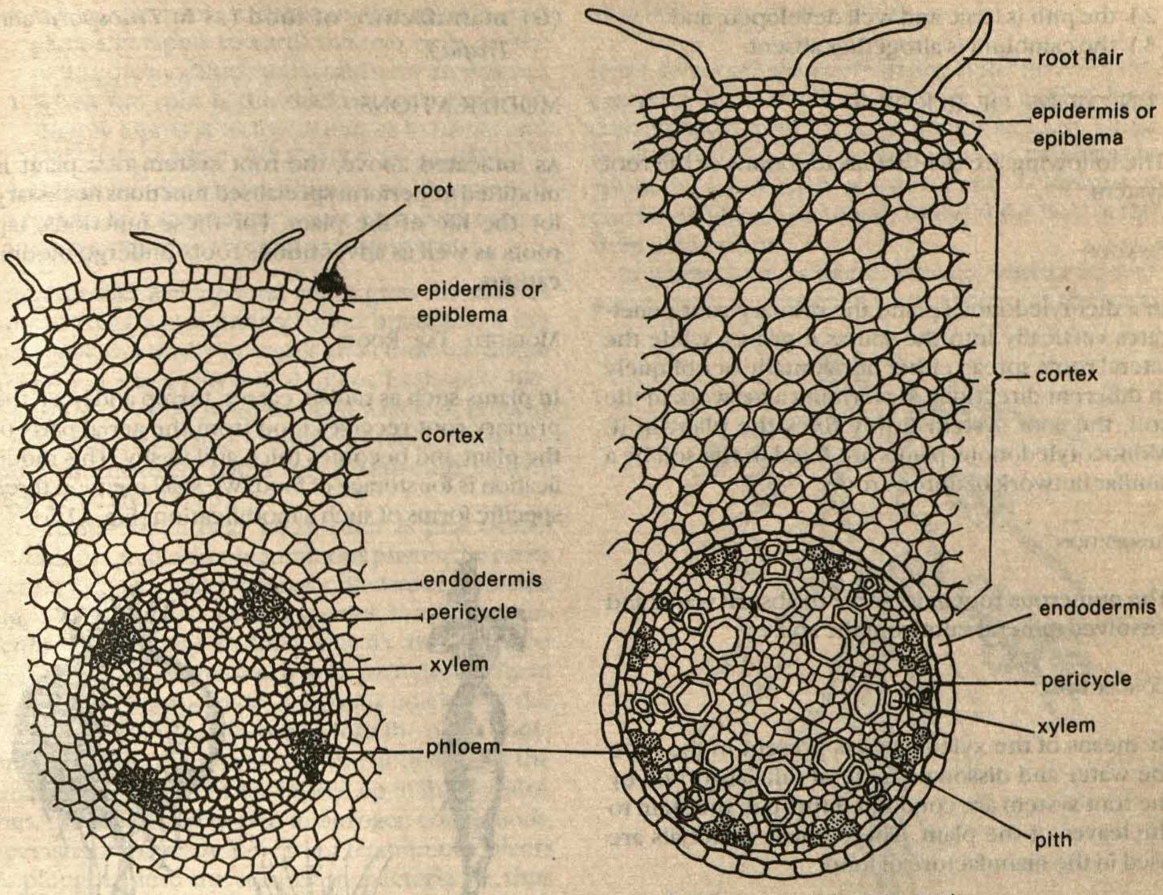


FIG. 11.3 Transverse section of a dicotyledonous root



(a) Dicotyledonous root

(b) Monocotyledonous root

FIG. 11.4 Internal structure of roots

stele (bulky strand or cylinder of tissue) [Figs. 11.4a and 4b].

The stele encloses within it the conducting vessels of the root, i.e., the **xylem** and the **phloem**. The outermost layer of the stele lies just inside the endodermis and is called the **pericycle**. It consists of a single layer of smaller and thin-walled cells. Inside the pericycle is the circular central region with separate radially arranged bundles of xylem and phloem. The number of bundles of xylem and phloem varies between 2 and 6, seldom going higher. The bundles of xylem and phloem, respectively, appear alternately at different radii in the stele. Between these vessels parenchyma cells are present. The **cambium** (a thin formative layer of multiplying cells) does not appear between the xylem and the phloem in a young root; it develops when secondary growth occurs in an older root. The **pith** (a continuous strand of spongy tissue along the actual axis of the root) occupies only a small area at the centre. Sometimes, when the xylem bundles meet in the centre, the pith is obliterated. The xylem consists of **tracheids** and vessels for transporting water and dissolved mineral salts upward into the stem. The phloem consists of sieve tubes and companion cells for transporting food prepared in the green leaves to root cells.

MONOCOTYLEDONOUS ROOT

When the internal structure of a monocotyledonous root, such as that of a maize plant, is examined under a microscope, the following differences are observed:

(1) the number of xylem and phloem bundles is not limited, and may be very high;

(2) the pith is large and well developed; and
(3) the cambium is altogether absent.

FUNCTIONS OF ROOTS

The following are the various functions of the root system.

FIXATION

In a dicotyledonous plant, the primary root penetrates vertically into the soil as it grows, while the lateral roots spread either horizontally or obliquely in different directions. By forming a network in the soil, the root system firmly fixes the plant in it. Monocotyledonous plants are fixed in the soil by a similar network of fibrous roots.

ABSORPTION

The numerous root hairs serve to absorb water and dissolved mineral salts from the soil.

CONDUCTION

By means of the xylem vessels present in the root, the water and dissolved mineral salts absorbed by the root system are conducted through the stem to the leaves of the plant. There, these materials are used in the manufacture of food.

STORAGE

Manufactured food, which is in excess of the immediate requirements of the plant, is stored in various parts. The food is conducted by the phloem. The root system stores some of the excess food in anticipation of later use.

SPECIALISED FUNCTIONS

In many cases, roots are modified to perform special functions. Some of these functions are as follows·

(1) **storage** of a large quantity of food (as in radish, carrot, turnip, beet, sweet potato, *Dahlia*, and so on).
(2) **breathing** (as in *Rhizophora*);
(3) **nitrogen fixation** (as in pea, beans, groundnuts, and other pod-bearing plants);
(4) **climbing** (as in ivy, money plant, betel and so on);
(5) **absorption of food** from a host plant (as in dodder); and
(6) **manufacture of food** (as in *Tinospora* and *Trapa*).

MODIFICATIONS

As indicated above, the root system of a plant is modified to perform specialised functions necessary for the life of the plant. For these functions, tap roots as well as adventitious roots undergo modifications.

MODIFIED TAP ROOTS

In plants such as radish, carrot, turnip and beet, the primary root receives food from the aerial parts of the plant and becomes thick and fleshy. This modification is for storage of food. We shall mention three specific forms of such a modification [Fig. 11.5].

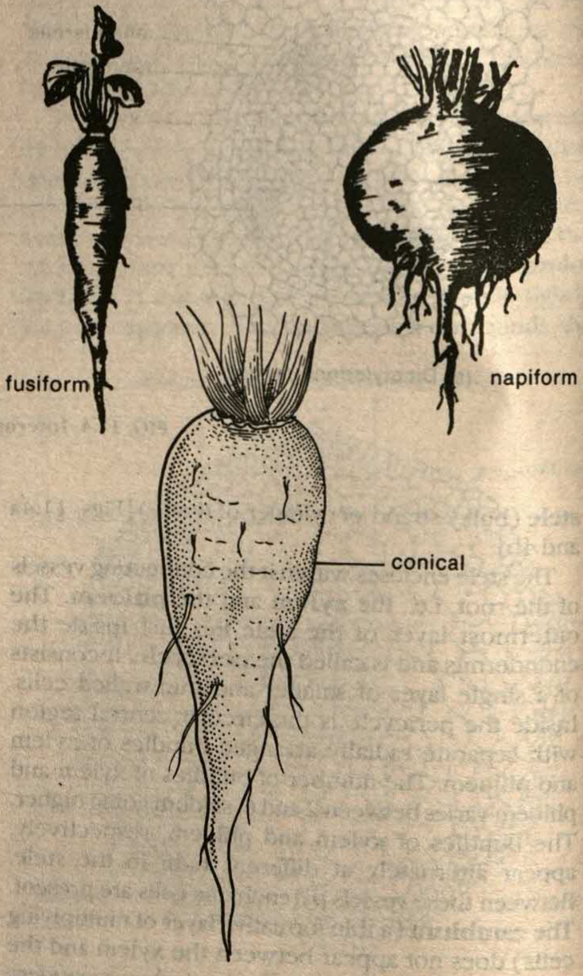


FIG. 11.5 Fusiform, napiform, and conical modifications of root

(1) When the root is thick in the middle and gradually tapers towards the two ends, as in a radish, the modified root is said to be **fusiform**.

(2) When the root is the thickest at its base and sharply tapers at its lower end, as in turnip and beet, the modified root is said to be **napiform**.

(3) When the root is the thickest at its base and gradually tapers at its lower end, as in carrot, the modified root is said to be **conical**.

In plants like *Rhizophora*, which grow in estuaries and salt lakes, some underground branches of the roots grow vertically upwards and come out at the surface in the form of conical spikes. Each spike-like root has many small holes through which air is taken in for respiration. Such modified branch roots are called **breathing roots** or **pneumatophores** [Figs. 11.6a and 11.6b].

In plants which bear pods, such as pea, beans, groundnuts, and other leguminous plants, the roots bear numerous small swellings called **root nodules** [Fig. 11.7]. Bacteria of the species *Bacillus radicicola* live in these nodules and fix the nitrogen present in the air between soil particles to form some amino compounds. A certain portion of the amino compounds is absorbed into the plant body; another portion comes out of the nodules and the remaining portion remains locked up in the nodules. Thus, the soil becomes rich in nitrogen compounds, especially if the nodule-bearing leguminous plants are ploughed into the soil. These bacteria are thus useful to leguminous plants. In return, these plants supply the bacteria with carbohydrates and shelter. Such a relationship of mutual benefit is known as **reciprocal symbiosis**.

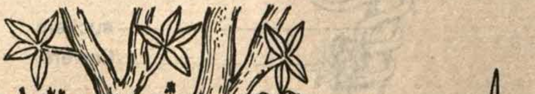


FIG. 11.6 Pneumatophores: A: Plant with pneumatophores and B: Pneumatophores growing vertically upwards from underground root

MODIFIED ADVENTITIOUS ROOTS

In the sweet potato, roots arising at the nodes of the creeping stem swell up because of excess food coming down from the aerial parts [Fig. 11.8]. These swollen roots are called **tuberous** or **tubercular roots**. In plants such as *Dahlia* and *Asparagus*, a cluster of tubercular roots is found at the base of the stem of the plant.

In plants such as maize, banyan, sugarcane, and screw pine, a number of roots appear on the main

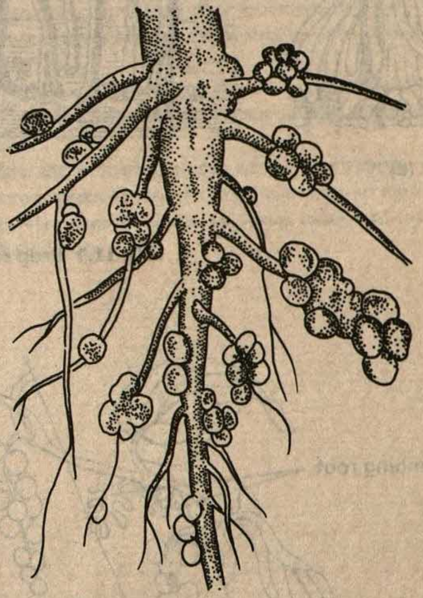


FIG. 11.7 Root nodules

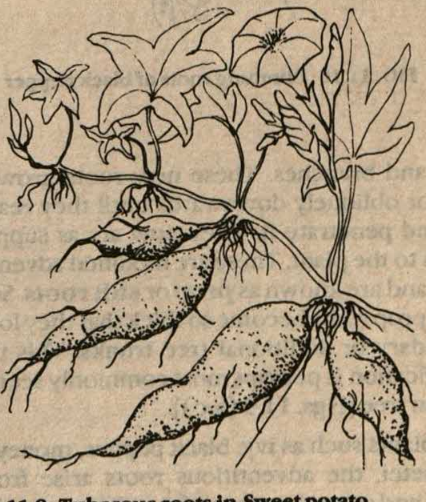


FIG. 11.8 Tuberous roots in Sweet potato

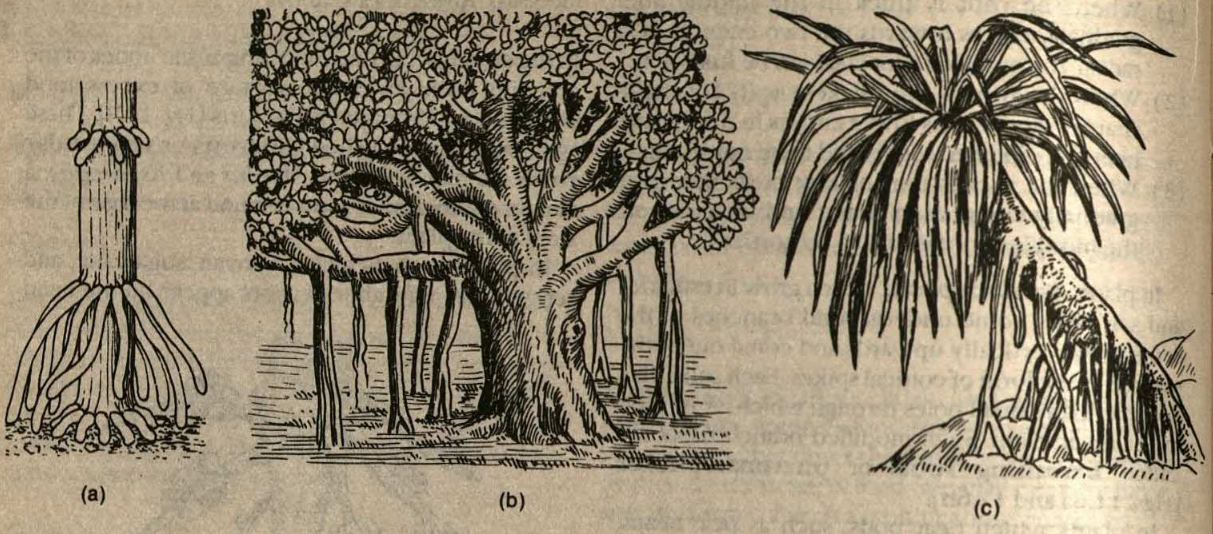


FIG. 11.9 Prop roots and stilt roots of different plants

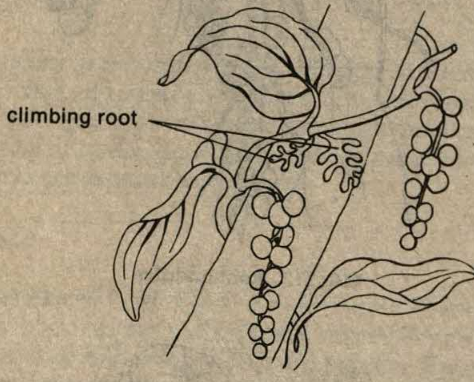


FIG. 11.10 Climbing roots of black pepper

stem and branches. These new roots grow vertically or obliquely downwards until they reach the soil and penetrate it. They now act as supporting pillars to the plant. These are modified adventitious roots and are known as **prop** or **stilt roots**. Some of these prop roots become so thick that they look like secondary or additional tree trunks. This type of modification is perhaps most commonly seen in the banyan tree [Figs. 11.9 (a-c)].

In plants such as ivy, black pepper, money plant, and betel, the adventitious roots arise from the nodes and sometimes even from the internodes and penetrate the cracks and crevices of the walls or supports on which these plants grow. Such roots are called **climbing roots** since they enable the plant to climb up a support [Fig. 11.10].

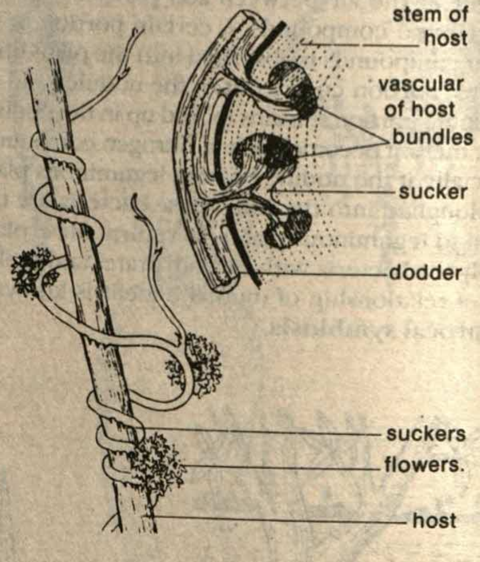


FIG. 11.11 Sucking roots of dodder

In the plants such as the dodder, which is a yellowish, leafless climber, adventitious roots, called **suckers**, arise from the stem and sink into the tissues of the host plant. These roots absorb water, mineral salts, and organic food material from the host. They are known as **parasitic** or **sucking roots** [Fig. 11.11]

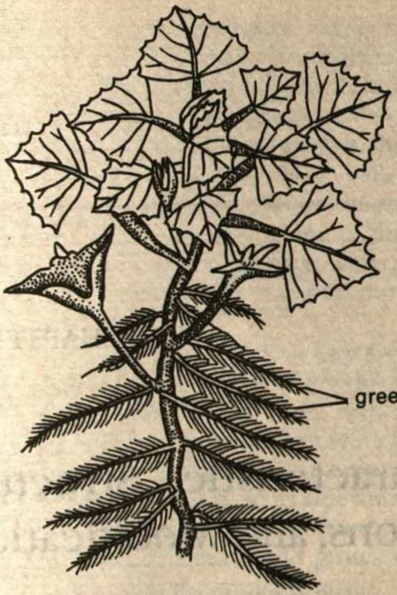


Fig. 11.12 Photosynthetic roots

Usually, roots are not green in colour. However, in plants such as *Tinospora* and *Trapa natans* (water chestnut), the roots contain chloroplasts and manufacture food just like leaves. Such roots are called **photosynthetic** or **assimilatory roots** [Fig. 11.12].

EXERCISES

1. State the five most important characteristics of roots.
2. What are the various important functions of roots?
3. (a) Briefly describe the internal structure of a dicotyledonous root.
   (b) How does it differ from a monocotyledonous root?
4. What are the distinctions between tap root and fibrous root systems?
5. Explain the following terms with two examples of each: (i) acropetal succession; (ii) root tubers; (iii) reciprocal symbiosis; (iv) parasitic roots; (v) prop roots; and (vi) photosynthetic roots.

CHAPTER 12

The Stem: Characteristics, Structure, Functions, and Modifications

CHARACTERISTICS OF THE STEM

The **stem** is the ascending organ of the plant which grows from the **plumule** of the seed. Usually, the stem of a flowering plant grows above the ground and bears branches, leaves, flowers, and fruits. The stem and the branches have a large number of nodes and multicellular shoot hairs.

The region along the stem between two adjacent nodes is called an **internode**. Leaves always arise at the nodes of a stem or its branches. The stem also bears small living structures called **buds**. Buds are of four kinds [Fig. 12.1].

(1) **Terminal or apical bud:** This bud is present at the apex or end of a stem or its branch.
(2) **Axillary or lateral bud:** This bud is present on the nodes in the axil of a leaf, i.e., in the angle between a leaf and a stem or its branch.
(3) **Vegetative bud:** This bud gives rise to further branches and helps the plant to grow and extend itself. A vegetative bud can be either terminal or axillary in position.
(4) **Reproductive or floral bud:** This bud gives rise to a flower. Like a vegetative bud, a reproductive bud also can be either terminal or axillary in position.

If the terminal bud is **vegetative**, it will give rise to further branches and the plant will grow and extend itself. If a bud is **reproductive (floral)**, it will give rise to flowers and will not enable the plant to grow at that point.

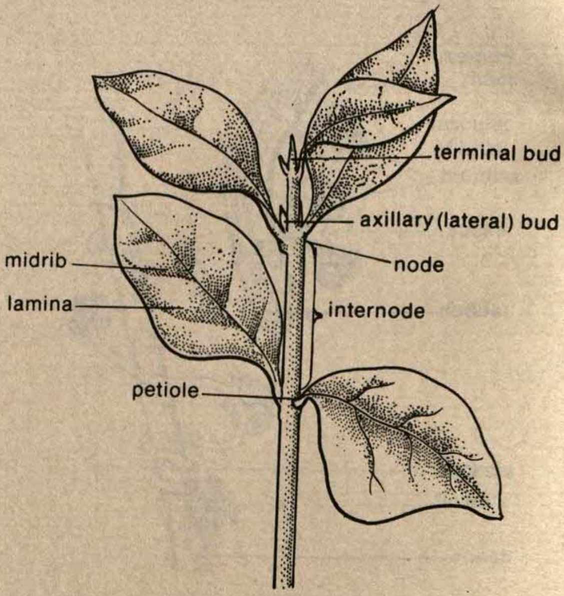


FIG. 12.1 Structure of stem

The branches always develop from a few outer layers of the cells of the stem and are said to be **exogenous**.

A vegetative bud is a young undeveloped shoot with a number of small closely placed overlapping leaves which enclose and protect the delicate apex of the stem. The apex consists of small, actively dividing cells. This is called the **apical meristem** or the **region of cell division**. Below this region lies the region of elongation or growth. New cells formed in the apical meristem migrate to the region of elongation where they undergo rapid elongation and enlargement and lead to growth in the length of the stem. Besides growing, these cells begin to undergo differentiation, specialisation, and maturation into various tissues according to the function that they have to perform later. This process is completed in a lower region called the region of maturation.

The stem, being aerial, grows upward from the ground, against the influence of gravity. It extends itself towards sunlight and away from moisture. These tendencies can be verified by a simple demonstration. If you have a flowering plant growing in a pot at home, place the pot on its side for a few days, you will find that the stem of the plant bends from its new horizontal position and grows vertical to the ground, towards the sunlight, again.

INTERNAL STRUCTURE OF THE STEM

Dicotyledonous Stem

If a very thin slice (transverse section) of a young sunflower stem is examined, first under a hand lens and then under a microscope, the following may be observed [Figs. 12.2 and 12.3].

Epidermis: This is the outermost layer which is one cell thick. It consists of closely fitted, thin-walled parenchyma cells. These cells do not contain chloroplasts except guard cells. In green stems the epidermal layer contains **stomata** (pores) which help in transpiration and exchange of gases. The outer walls of the epidermal cells are covered with a thin layer of a chemical called **cutin**. This layer is called the **cuticle**, and its functions are to protect the plant from mechanical damage and to prevent excessive loss of water from the plant. The function of the epidermis as a whole is chiefly protective.

Cortex: This is the region between the outer epidermis and the central region reserved for the conducting tissues of the plant. The cortex consists of three kinds of tissues, namely, the **hypodermis**, the **general cortex**, and the **endodermis**.

The hypodermis is the tissue just inside the epidermis. It consists of three or four layers of **collenchyma** cells. These small cells have their cell walls thickened at the corners and help in giving rigidity (mechanical strength) to the stem. These cells are alive and contain chloroplasts, which help in the manufacture of food.

The general cortex is the region just inside the hypodermis which consists of a few layers of large, thin-walled parenchyma cells. These cells are loosely fitted and have air spaces between them.

The endodermis is the innermost layer of the cortex and consists of rectangular cells. These cells store numerous starch grains within themselves, because of which the endodermis is often called the **starch sheath** of the stem. This layer surrounds the inner, central region of the stem, called the **stele**.

Stele: This region of the stem contains the **vascular system**. A vascular system is a system of tissues carrying the fluids (mineral salts and prepared food substances dissolved in water) which are essential to life in the organism. In higher animals the vascular system consists of blood vessels. In the stem of a green plant, the vascular system consists of the conducting tissues **xylem** and **phloem** in the form of **vascular bundles**. These bundles are arranged in rings around the core of the stem; each bundle containing the xylem (which conducts water and mineral salts from the roots to the leaves) and the phloem (which conducts synthesised food materials from the leaves to various parts of the plant). The xylem lies closer to the centre in the bundle.

The stele contains the following three structures:

The **pericycle** is a region of dead, thick-walled sclerenchyma tissue lying between the endodermis and the vascular bundles. It serves to support the stem.

The **cambium** is a region of living narrow, thin-walled parenchyma cells which separates the xylem from the phloem within each vascular bundle. These cells divide and multiply and add new cells to the xylem and the phloem. This leads to an increase in the thickness of the stem, which is part of the secondary growth of the plant.

The **pith** occupies the centre of the stem and contains large, living **parenchyma** cells. These cells also extend radially outward from the pith and between the vascular bundles and form **medullary rays**. These rays help store and conduct radially synthesised food material.

Monocotyledonous Stem

A young **monocotyledonous** stem, such as that of maize, differs from a young **dicotyledonous** stem in the following ways:

(1) The hypodermis consists of dead, thick-walled **sclerenchyma** cells.

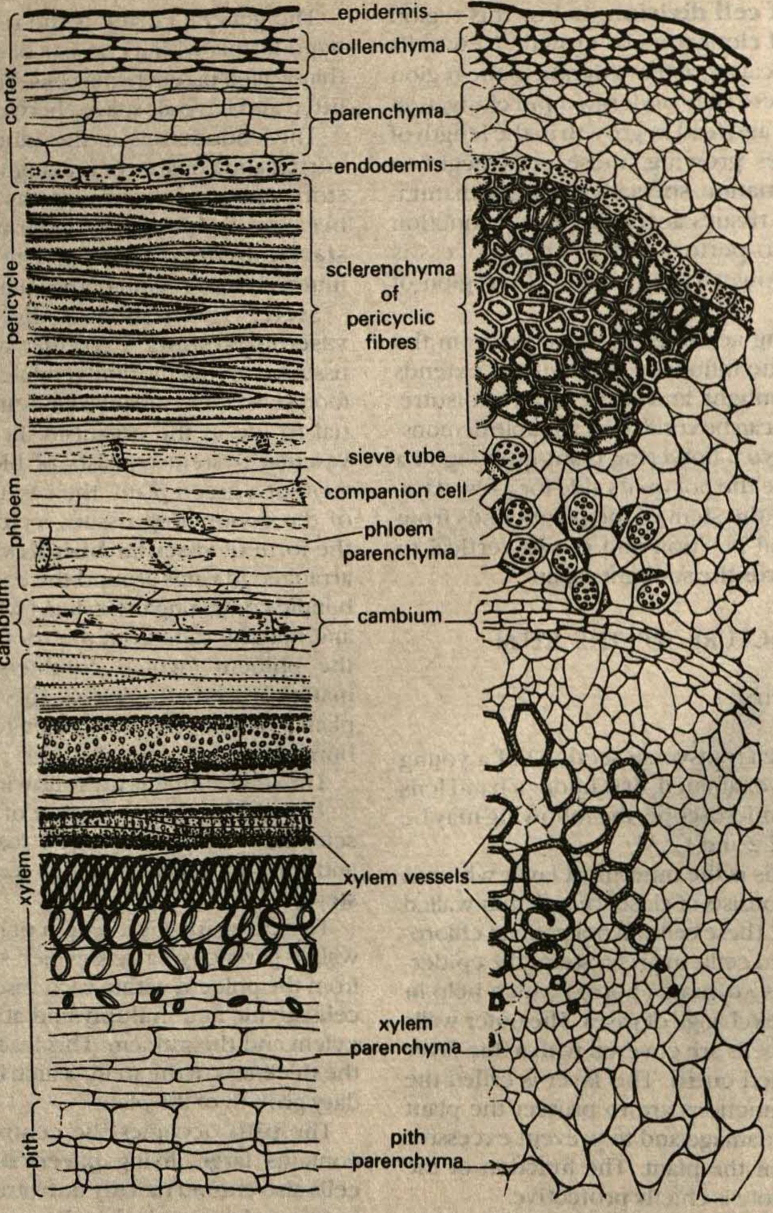


FIG. 12.2 Longitudinal and transverse sections of sunflower showing internal structure

(2) The general cortex is a continuous mass of living **parenchyma** cells extending right up to the centre of the stem.
(3) There is no endodermis.
(4) The medullary rays are not marked out.
(5) The pith is not marked out.
(6) The vascular bundles are scattered throughout the general cortex, with the larger ones placed closer to the centre of the stem.
(7) There is no cambium at all.

FUNCTIONS OF THE STEM

The following are some of the more important functions of the stem in the life of plant:

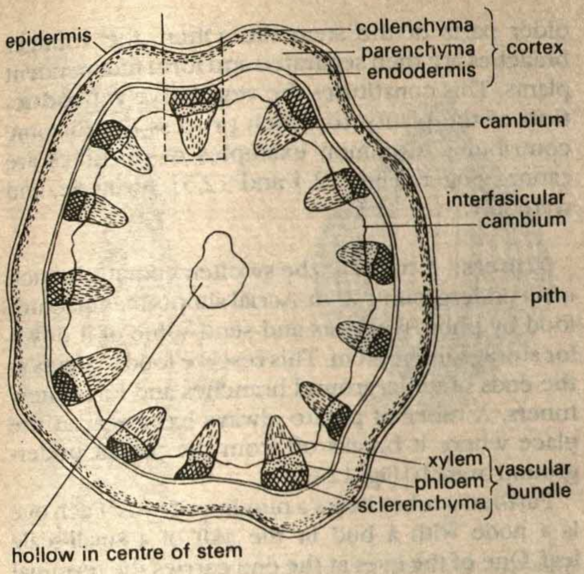


FIG. 12.3 Transverse section of sunflower stem

(1) The stem conducts water and dissolved mineral salts from the roots to the leaves by means of the xylem tissue that it contains.

(2) The stem also conducts synthesised material from the leaves (and other green parts) to the storage organs and to the growing parts of the plant. This is done by means of the phloem tissue in the stem.

(3) The main stem bears the weight of the branches and leaves and is the chief mechanical support of the plant.

(4) The stem also serves to store food and water. For example, in the modified stems of plants such as potato, ginger, and *Colocasia* food is stored, whereas in the fleshy stems of the **cacti** and **spurges**, large quantities of **water** are stored.

(5) The stem of a young plant is usually green, and, as such, helps the plant in manufacturing food by photosynthesis. In older plants (especially trees) the stem often does not perform this function.

(6) The main stem and its branches grow in such a manner that the leaves of the plant are spread out to gain maximum exposure to sunlight for photosynthesis. Similarly, they also distribute the flowers of the plant in such a way as to attract insects from all directions for pollination and fertilisation.

(7) Modified stems perform specialised functions; e.g., **stem tendrils** help in climbing and **thorns** protect against grazing animals.

MODIFICATIONS OF THE STEM

All stems are well suited to perform the basic functions of transportation of water, dissolved mineral salts, and synthesised food material. However, some plants require other functions for their survival and growth, and stems are often modified to perform these special functions. Modifications of stems may occur in three possible cases, as observed:

(1) In some plants, the entire stem remains underground; only leaves and flowering shoots emerge above the ground. The underground stem is modified to store excess food, which enables the plant to survive through long periods of unfavourable conditions. The ability to survive through bad seasons is called **perennation**.

(2) Some plants reproduce without seeds, by means of underground and subaerial modifications of the stem (e.g., potato and grass). This is known as **vegetative reproduction**.

(3) Some plants have stems and branches which are not rigid enough to hold themselves erect. The leaves also cannot be held up to sunlight for photosynthesis. In such cases, the stems and branches are modified to seek external supports and to climb along them.

UNDERGROUND MODIFICATIONS

Stems which have to live underground for survival lie dormant and leafless in the soil during unfavourable conditions. Every year, during a good season, i.e., when conditions turn favourable, they send up aerial shoots. Such stems are thick and fleshy; they contain a large quantity of reserve food. Such modified underground stems are often mistaken for roots, as in the case of tubers of potato and the rhizomes of ginger. They can be distinguished from roots since (1) they have nodes and internodes; (2) they bear leaves, which are reduced to brown, membrane-like structures called **scale leaves**; (3) they bear axillary buds (at the nodes with scale leaves) and often a terminal bud also; (4) they have no root caps; and (5) their internal structure resembles that of aerial stems and not that of roots.

The main functions of underground stems are: (1) perennation; (2) storage of food; and (3) vegetative reproduction. The various types of modified underground stems are described as follows:

Rhizomes: A **rhizome** is a thickened stem with a horizontally branched structure which grows underground slowly. It bears nodes, internodes, scale leaves, axillary buds, a terminal bud, and some slender adventitious roots. Most of the time, a rhizome is **dormant**. However, during a favourable season, the terminal and axillary buds grow into aerial shoots. These new shoots are green and manufacture food in the presence of sunlight above the ground. This food is stored in the rhizome in the form of starch, and is used during unfavourable conditions. When the favourable season ends, the aerial shoots wither away and die. As the branched structure of the rhizome spreads underground, older parts of the stem die. Often, the younger branches are then separated and form independent plants. This constitutes the **vegetative reproduction** of the plants, to which process the rhizome contributes. Common examples of rhizomes are canna, ginger [Figs. 12.4 and 12.5], turmeric, and water lily.

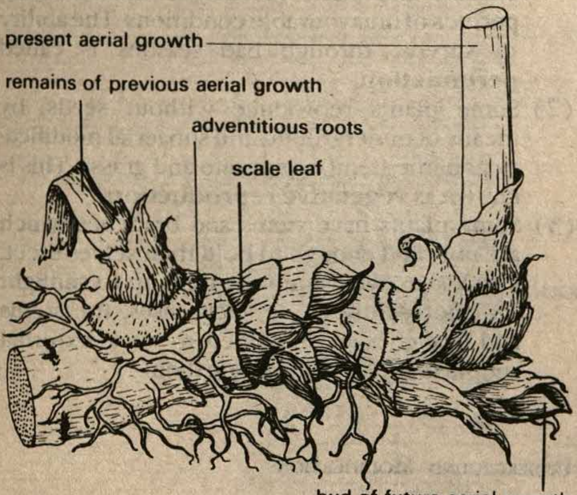

present aerial growth
remains of previous aerial growth
adventitious roots
scale leaf
bud of future aerial growth

FIG. 12.4 Structure of rhizome of canna

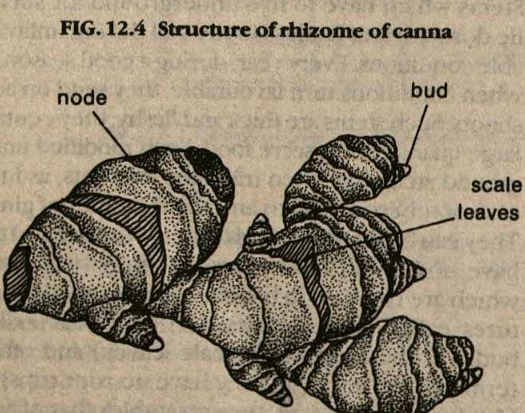


FIG. 12.5 Structure of rhizome of ginger

Tubers: A **tuber** is the swollen end of a branch of an underground stem. Aerial shoots manufacture food by photosynthesis and send some of it down for storage in the stem. This reserve food collects at the ends of underground branches and forms new tubers. A tuber of potato always has a scar at the place where it breaks off from the parent underground branch [Fig. 12.6].

Further, a tuber bears a number of eyes. Each eye is a node with a bud in the axil of a small-scale leaf. One of the eyes at the end carries the terminal bud. Pieces of a tuber that bears eyes with buds are used for growing new plants by employing vegetative reproduction.

Bulbs: A **bulb** is a small, rounded, and slightly conical underground stem. It consists of a **disc** which bears a mass of large, overlapping scale leaves and a terminal bud above, and a cluster of adventitious roots below. The outer scale leaves of the bulb are dry and membrane-like, and they protect the thick, fleshy inner scale leaves which store food and water. The latter variety of leaves have axillary buds at their axils; some axillary buds may give rise to green aerial shoots and grow into daughter bulbs which may be detached from the parent bulb and become independent plants. The terminal bud gives rise to green aerial shoots in a favourable season. These shoots manufacture food, some of which is stored for use during unfavourable times. Common examples of bulbs are onion [Fig. 12.7], garlic, tuberose, and lilies.

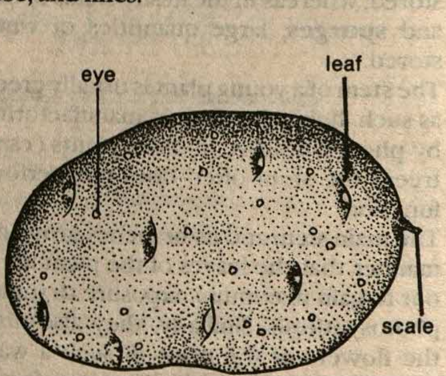


FIG. 12.6 Structure of tuber of potato

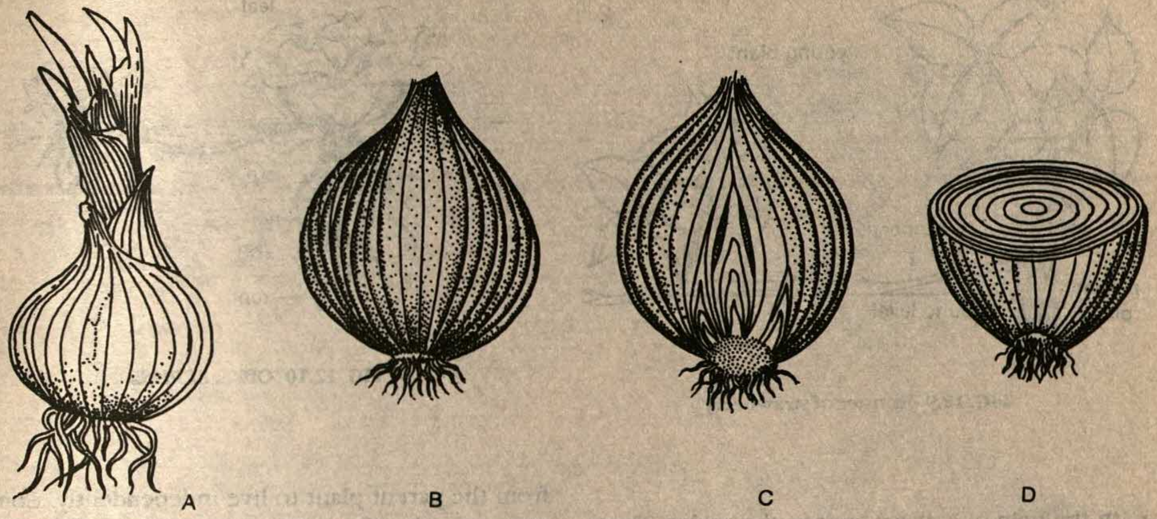


FIG. 12.7 Structure of bulb of onion: A: An entire bulb with foliage leaves; B: An entire bulb without foliage leaves; C: A bulb, cut longitudinally; and D: A bulb cut transversely

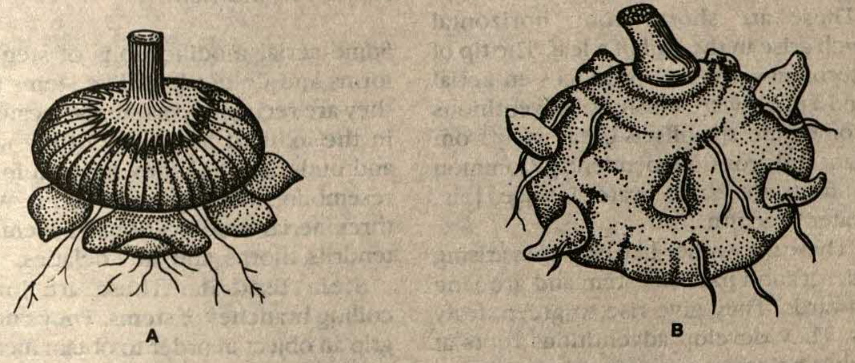


FIG. 12.8 Structure of corm: A: Corm of *Gladiolus* and B: Corm of *Amorphophallus*

Corms: A corm is the swollen, more or less rounded, underground base of a vertical stem. It usually bears brown scales on the outside, which are, in fact, remains of leaf bases at the nodes. Nodes and internodes are quite distinctly visible. Scale leaves provide the covering of the corm; they bear axillary buds at their axils, and some of these buds grow into daughter corms. At the beginning of a favourable season, the terminal bud of the corm gives rise to green aerial shoots with leaves. During such a season, excess food in the form of starch collects at the base of the corm and forms a new corm at the top of the old one, which has shrunk by that time. Starch may collect in axillary buds in a similar way and give rise to daughter corms as noted earlier. Daughter corms may separate themselves from the parent and give rise to new plants. Thus corms also help in vegetative reproduction. Common examples of corms are crocus (saffron), *Gladiolus*, *Amorphophallus*, and *Colocasia* [Fig. 12.8].

SUBAERIAL MODIFICATIONS

Subaerial modifications occur only for the sake of vegetative reproduction. Such modifications take the following forms.

Runners: These are long, thin branches bearing axillary buds at the nodes and spreading horizontally over the ground. Each runner has nodes and long internodes; at each node aerial shoots are formed above and adventitious roots below [Fig. 12.9]. Several runners are produced by a single parent plant

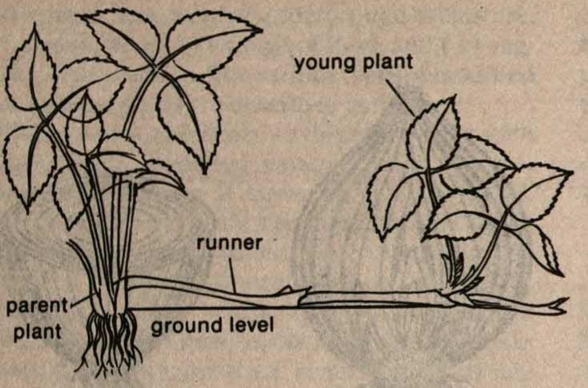


FIG. 12.9 **Runner of strawberry**

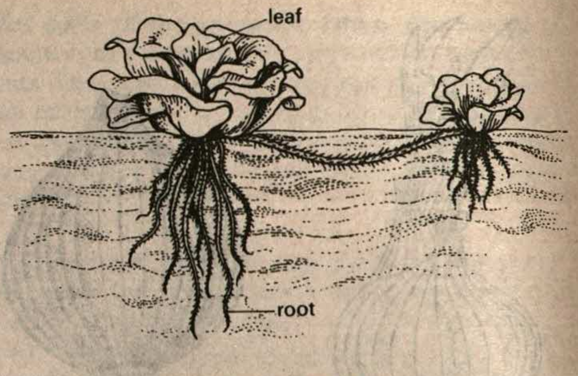


FIG. 12.10 **Offset of *Pistia***

with the help of axillary buds at the nodes. These runners grow separately and independently when older parts die. Common examples of runners are lawn grass, strawberry, and *Oxalis* (wood sorrel).

Offsets: These are short, stout, horizontal branches which arise in the axil of a leaf. The tip of each offset turns upward and produces an aerial leafy shoot and a downward cluster of adventitious roots. After some time, the offsets break away from the parent plant and grow independently. Common examples of offsets are *Pistia* (water lettuce) [Fig. 12.10] and water hyacinth.

Suckers: These are runner-like branches arising from the underground part of a stem and growing obliquely upwards. They give rise to green, leafy aerial shoots. They develop adventitious roots at their base either before or soon after they separate from the parent plant to live independently. Common examples of suckers are mint, *Chrysanthemum*, banana [Figs. 12.11 (a) and 12.11 (b)] and pineapple.

AERIAL MODIFICATIONS

Some aerial modifications of stems take peculiar forms and do not look like stems at all. However, they are recognised as stems because (1) they arise in the axils of leaves; (2) they may bear leaves and buds; and (3) they have an internal structure resembling that of genuine stems. We now describe three aerial modifications of stems, namely, stem tendrils, thorns, and phylloclades.

Stem tendrils: These are long, thread-like, coiling branches of stems. They enable the plant to grip an object in order to obtain mechanical support for climbing. A tendril may also be a modification of

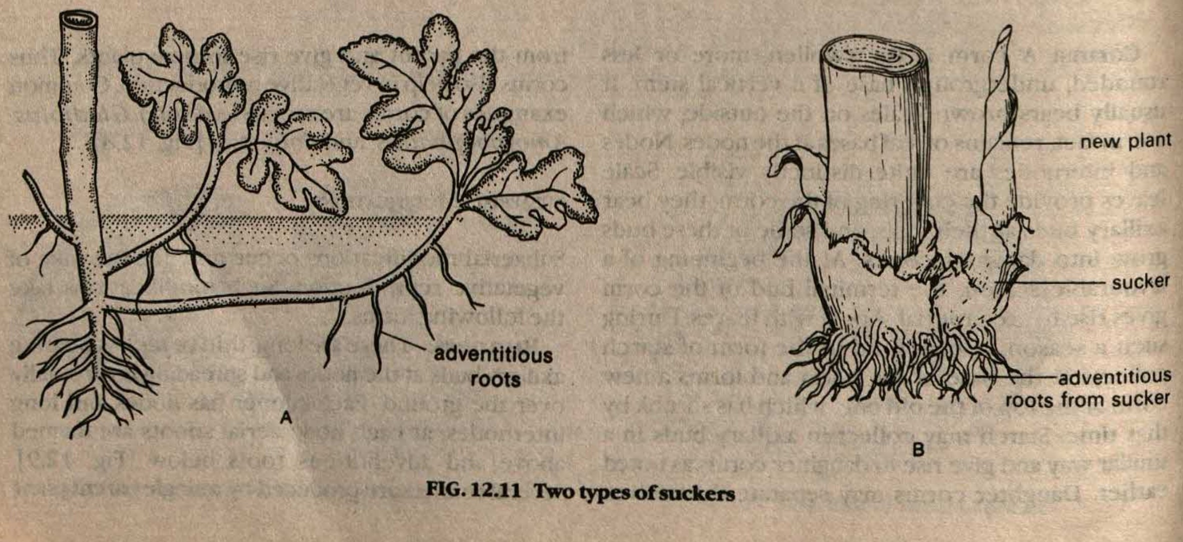


FIG. 12.11 **Two types of suckers**

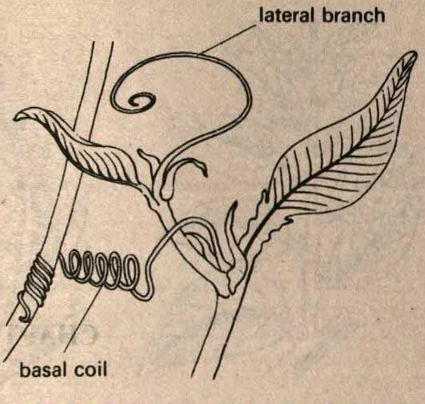


FIG. 12.12 Stem tendril of passion flower

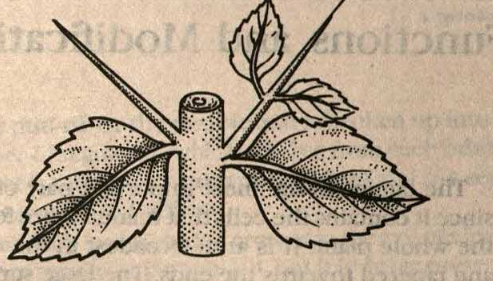


FIG. 12.13 Thorns of *Duranta*

an axillary bud, as in a passion flower [Fig. 12.12] or of an inflorescence axis, as in balloon vine and *Antigonon* (Sandwich Island climber).

Thorns: These are hard, sharply pointed, usually straight modifications of either axillary buds, as in *Duranta* [Fig. 12.13] and *Citrus* (lemon), or terminal buds, as in *Carissa*. Sometimes, thorns are branched, or else they bear leaves, flowers, and fruits. Usually, they are used as organs of defence, but they may also be used for climbing, as in *Bougainvillea*.

Phylloclade: In plants growing in dry climates, often, the leaves do not develop into green structures, being modified into spines or scales. In such cases, the stem becomes flattened or cylindrical (sometimes even leaf-like), and being green, functions like the leaf. Thus, it is modified to manufacture food by photosynthesis, for the plant. It also functions as a storage organ, storing plenty of water. Common examples are cacti [Fig. 12.14] such as prickly pear, *Epiphyllum*, some species of *Euphorbia*, *Cocoloba*, and *Casuarina*.

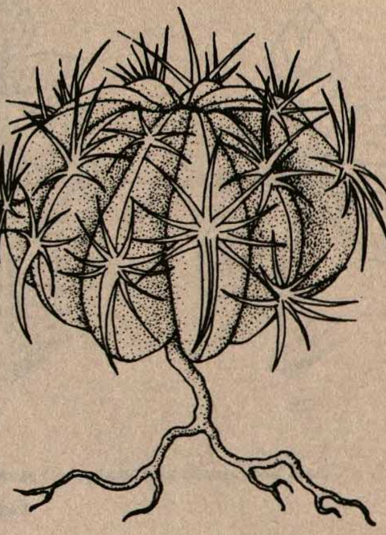


FIG. 12.14 Phylloclade of cactus

EXERCISES

1. Make a table comparing the characteristics, functions, and modifications of roots and stems.
2. What are the important functions of stems?
3. Briefly describe the internal structure of a dicotyledonous stem. How does it differ from that of a monocotyledonous stem?
4. What do you understand by the terms 'perennation' and 'vegetative reproduction'? How are stems adapted to perform these functions? Explain with the aid of examples.
5. Describe the features and functions of the following modifications of stems, with appropriate examples: (i) stem tubers; (ii) offsets; (iii) rhizomes; (iv) phylloclade; (v) bulbs: and (vi) corms.

CHAPTER 13

The Leaf: Characteristics, Structure, Functions, and Modifications

CHARACTERISTICS OF THE LEAF

A **leaf** is usually a green thin, flat, broadened structure arising from a stem or a branch. It always grows at a node. The entire set of leaves of a plant is known as its **foliage**. Leaves grow on a plant in an **acropetal order**; that is, the younger and smaller leaves are closer to the growing apex, whereas the older and larger leaves are further away from it.

A typical leaf has three distinct parts: a **leaf blade** or **lamina**; a **stalk** or **petiole**, and a **leaf base** [Fig. 13.1]. The leaf base is located at the junction of the petiole and the stem or branch of the plant. The angle between the petiole and the stem is called the **axil**. Usually, there is an axillary bud in the axil of a leaf.

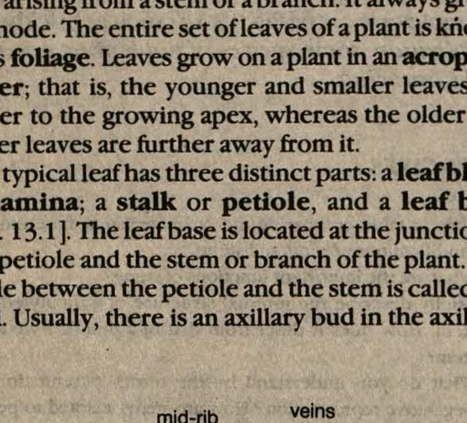


FIG. 13.1 Strucrure of a typical leaf

The lamina is the most important part of a leaf since it contains the cells that manufacture food for the whole plant. It is at its broadest in the middle and tapered towards the ends. The large surface of the lamina is well adapted to absorb sunlight energy and carbon dioxide for photosynthesis. The end of the lamina joining the petiole is called its **base**, while the free end is called its **apex**. In a simple leaf, a strong, stout **vein** called the **mid-rib** runs from the base to the apex through the lamina. Comparatively thin veins branch out from the mid-rib on both sides. Each such vein further branches out into many **veinlets** in the lamina. The mid-rib, the veins, and the veinlets together form a complete network which keeps the lamina sufficiently stiff and flat for its functions. The **venation** constitutes the skeleton of the leaf and also contains the conducting tissues—xylem for conducting water and mineral salts to the leaf cells and phloem for conducting food manufactured in the leaf cells to all other parts. In some leaves, the leaf base is swollen and is called **pulvinus**. In many leaves, a pair of small, leaf-like structures, called **stipules**, appear at the leaf base. Figure 13.2 depicts different types of leaves.

COMPOUND LEAVES

A simple leaf consists of a single lamina which may be entire or **lobed** to any depth, but not down to the mid-rib or the petiole. If the lamina is lobed up

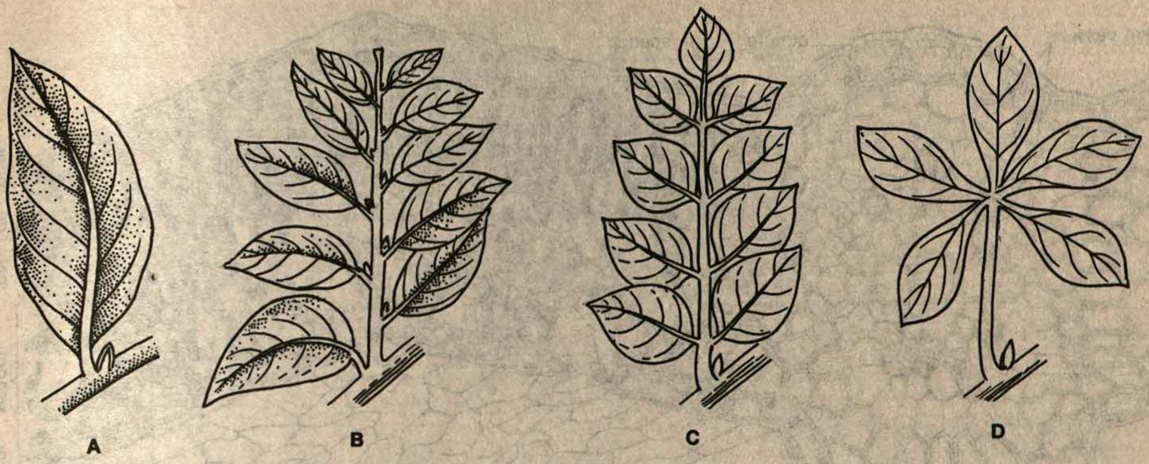


FIG. 13.2 Different types of leaves: A: A simple leaf; B: A branch; C: A pinnately compound leaf; D: A palmately compound leaf

to the mid-rib or the petiole and is broken up into a number of segments, which are free from each other, the leaf is said to be a **compound leaf** and the segments are called **leaflets**.

An axillary bud is always present in the axil of a leaf, whether simple or compound, but it is never present in the axils of the leaflets of a compound leaf. Sometimes, a large compound leaf may be mistaken for a branch and its leaflets for leaves. However, a careful observation enables us to distinguish between a compound leaf and a cluster of simple leaves on a branch. The following are the distinctions between the two:

(1) There is an axillary bud in the axil of the petiole of a compound leaf, whereas a branch itself arises from the axil of a leaf and carries no bud in its axil.
(2) The leaflets of a compound leaf do not have buds in their axils, whereas simple leaves on a branch always have buds in their axils.
(3) A compound leaf never bears a terminal bud, whereas a branch always bears such a bud.
(4) A compound leaf never arises in the axil of another leaf, whereas a branch arises in the axil of a simple or compound leaf.

INTERNAL STRUCTURE OF LEAVES

Dicotyledonous Leaf

A typical leaf of a **dicotyledonous plant** has a flat lamina which is supported on the plant in a horizontal position. The upper surface of such a leaf is exposed to light to a great extent during the day, whereas the lower surface rarely gets direct light. Consequently, the upper surface is coloured a much deeper green than the lower surface; such a leaf is called a **dorsiventral** leaf. When a thin slice (transverse section) of a dorsiventral leaf is examined under a microscope, the following may be observed [Fig. 13.3].

Epidermis: The entire leaf has a one-cell thick outer layer called the **epidermis**. This epidermis is made up of thin-walled parenchyma cells closely arranged together (with no air spaces between them). It is continuous over the edges of the leaf and, only for the sake of convenience, may be divided into the **upper epidermis** (on the upper surface of the lamina) and the **lower epidermis** (on the lower surface of the lamina). The epidermal cells secrete a wax-like, water-proof chemical substance called **cutin**, which forms a thin layer called **cuticle** outside the upper and lower epidermis. (The cuticle is usually comparatively thinner on the lower epidermis.) The cuticle prevents the drying up of the underlying tissues by checking the excessive evaporation of water and also protects them against mechanical and other kinds of injuries.

On the upper surface, none of the epidermal cells contains chloroplasts and this layer is transparent. Sunlight is allowed to pass through to the lower layers of cells containing chloroplasts for carrying out photosynthesis.

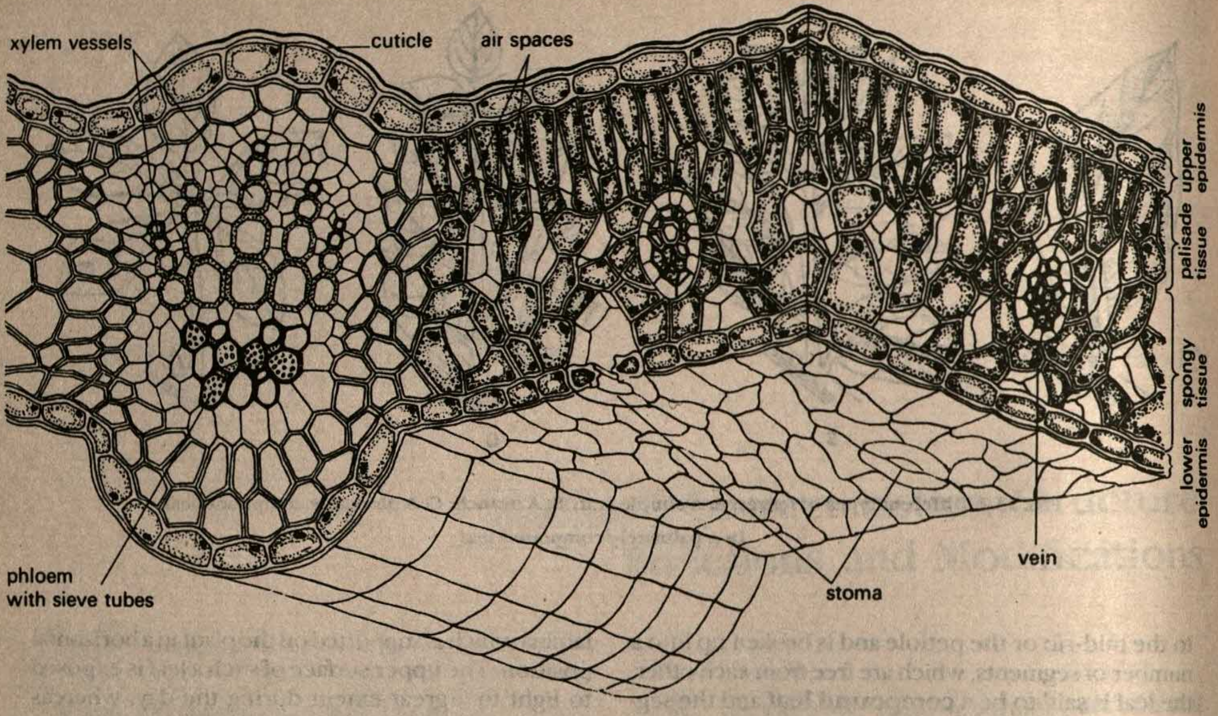


FIG. 13.3 Stereogram of leaf, showing internal structure in transverse section and part of external surface

On the lower surface, the epidermal cells have between them numerous tiny openings called **stomata** (singular: **stoma**) [Fig. 13.4]. A stoma is a small opening between two highly specialised epidermal cells called **guard cells**. These two cells are bean-shaped and are attached to each other by the curved ends of their concave sides. The walls of the guard cells are thicker on their inner concave sides and thinner on their outer convex sides. Unlike the ordinary epidermal cells, the guard cells contain chloroplasts. Usually, no stomata are found in the upper epidermis. However, if present in some cases, they are very few in number. Beneath each stoma lies a substomatal chamber, which is a large respiratory cavity [Fig. 13.3].

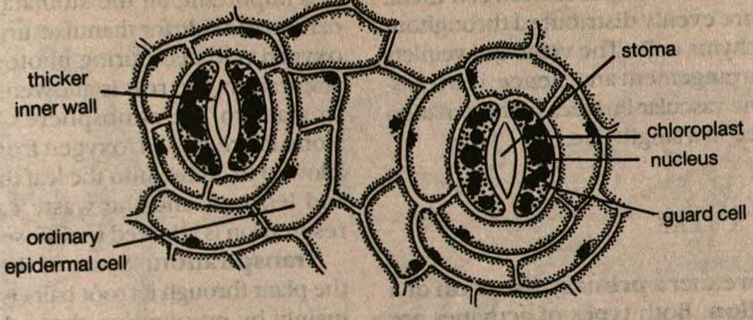
We may summarise the functions of the epidermis as follows:

(1) The epidermis, with its cuticle, helps in maintaining the shape of the leaf.
(2) The cuticle prevents bacteria and fungi from attacking the inner cells, and protects the leaf against mechanical damage.
(3) The epidermis is transparent and thus allows sunlight to reach the mesophyll cells containing chloroplasts for photosynthesis.
(4) The stomata in the epidermis help in transpiration. They also enable the leaf to exchange gases with the atmosphere.

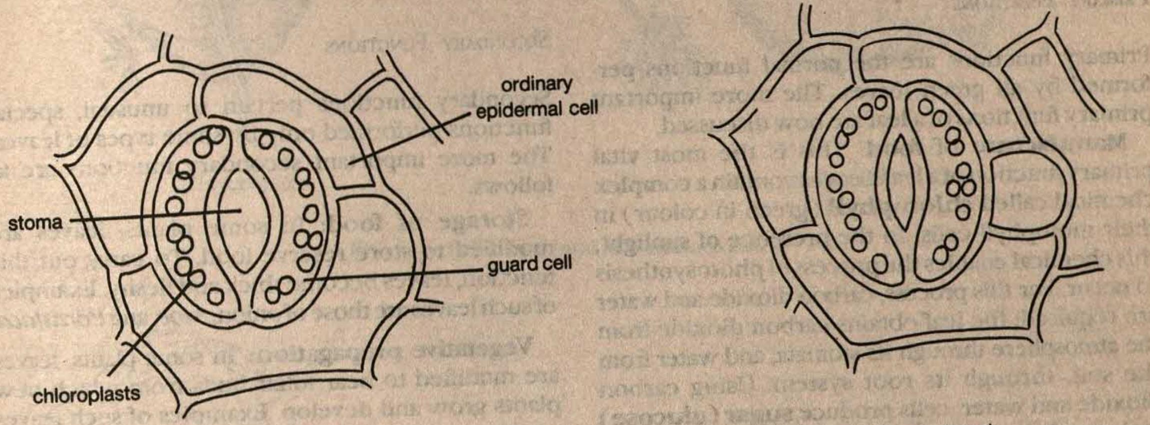
Mesophyll tissue: Between the lower and upper epidermal layers lies the ground tissue called the **mesophyll tissue**. This tissue consists of a layer of specialised parenchyma cells. This layer is several cells thick. In fact, mesophyll tissue constitutes most of the thickness of the leaf. The two types of special parenchyma cells it contains are now briefly described.

First, **palisade parenchyma cells** [Fig. 13.3] are tightly arranged in one or two layers, with their longer sides perpendicular to the epidermis. This arrangement of cells and the presence of numerous chloroplasts in these cells give the upper surface of the leaf a much darker colour than the lower one. It should be noted that palisade parenchyma cells can carry out photosynthesis.

Secondly, **spongy parenchyma cells** [Fig. 13.3] are loosely and irregularly arranged, with large air spaces between them. These air spaces are connected to the outside atmosphere by means of the stomata. This fact can easily be verified: Place a large leaf in hot water (at about 80°C). The air in the



(a) Surface view of leaf showing stomata on epidermal surface



(b) Stoma open

(c) Stoma closed

FIG. 13.4 Epidermal cells and the enclosed stomata

internal air spaces expands and can be seen escaping in bubbles formed on the two surfaces of the leaf. The number of bubbles formed on the lower surface is far more than that on the upper one. Spongy parenchyma cells also contain some chloroplasts (less than the palisade parenchyma cells) and help in photosynthesis.

Vascular bundles: The conducting tissues, namely, the xylem and the phloem, are contained in vascular bundles (in the mid-rib), and in the veins and the veinlets distributed throughout the lamina. Each bundle contains the xylem, placed closer to the upper epidermis, and the phloem, placed closer to the lower epidermis. The xylem distributes water and dissolved mineral salts (conducted from the roots through the stem) to the various cells containing chloroplasts in the lamina. The phloem carries synthesised food materials from the mesophyll cells to different growing and storage parts of the plant. Each vascular bundle is encased in a one-cell thick layer of thin-walled **border parenchyma cells**. Rigidity is provided to the vascuiar bundles by patches or sheaths of **sclerenchyma cells** present around them.

MONOCOTYLEDONOUS LEAF

Since the leaves of a monocotyledonous plant are not supported horizontally, both their surfaces are equally exposed to sunlight, and are equally green. Such leaves are called **isobilateral leaves.**

In an isobilateral leaf, one cannot identify precisely the upper and the lower surfaces. The epidermis on both surfaces bears stomata, and the cuticle is uniformly thick everywhere. Usually, the mesophyll layer in the monocotyledonous leaf consists of only spongy parenchyma cells, with large intercellular cavities and air spaces between them. The chloroplasts are evenly distributed throughout the spongy parenchyma cells. The veins and veinlets are all parallel in arrangement and, hence, in a transverse section, all the vascular bundles in the venation appear to be placed in a single line.

FUNCTIONS OF A LEAF

A leaf may perform either a **primary function** or a **secondary function**. Both types of activities are now described.

PRIMARY FUNCTIONS

Primary functions are the normal functions performed by all green leaves. The more important primary functions of a leaf are now discussed.

Manufacture of food: This is the most vital primary function of a leaf. Leaves contain a complex chemical called **chlorophyll** (green in colour) in their mesophyll cells. In the presence of sunlight, this chemical enables the process of photosynthesis to occur. For this process, carbon dioxide and water are required; the leaf obtains carbon dioxide from the atmosphere through its stomata, and water from the soil, through its root system. Using carbon dioxide and water, cells produce **sugar (glucose)** and **starch** by photosynthesis. Plants usually store food in the form of starch.

Exchange of gases: This primary function is carried out with the help of **stomata**, which remain open only during daylight. The opening and closing of the stomata are controlled by the two guard cells surrounding each one of them. An exchange of gases between the leaf and the atmosphere takes place for two purposes:

(1) **Respiration** requires that oxygen be taken in from the atmosphere. Carbon dioxide is released as a waste product during respiration, and is given out to the atmosphere through the stomata.

(2) **Photosynthesis** requires that carbon dioxide be taken in from the atmosphere. Oxygen is released during this process and some of it diffuses back to the atmosphere through the stomata.

Photosynthesis occurs only during the daytime, whereas respiration occurs during the daytime as well as during the night. During the day, the occurrence of photosynthesis makes respiration less important; all the stomata are open to take in carbon dioxide for manufacturing food. Some of the oxygen released during photosynthesis is used for respiration; the rest is allowed to diffuse out of the stomata to the atmosphere. At night, when the stomata are closed, oxygen from the atmosphere is allowed to diffuse into the leaf through the epidermis and lenticels and the waste carbon dioxide from respiration is allowed to diffuse out.

Transpiration: Some of the water absorbed by the plant through its root hairs is lost during daytime, mainly by evaporation through the open stomata. This process is called **transpiration**. It helps control the water content of the plant.

SECONDARY FUNCTIONS

Secondary functions pertain to unusual, special functions performed only by some types of leaves. The more important secondary functions are as follows.

Storage of food: In some plants, leaves are modified to store reserve food. To carry out this function, leaves become thick and fleshy. Examples of such leaves are those of onion, *Aloe*, and *Portulaca*.

Vegetative propagation: In some plants, leaves are modified to bear foliar buds from which new plants grow and develop. Examples of such leaves are those of *Bryophyllum* (sprout-leaf plant) and *Begonia* (elephant-ear plant) [Figs. 13.5 (a) and 13.5 (b)].

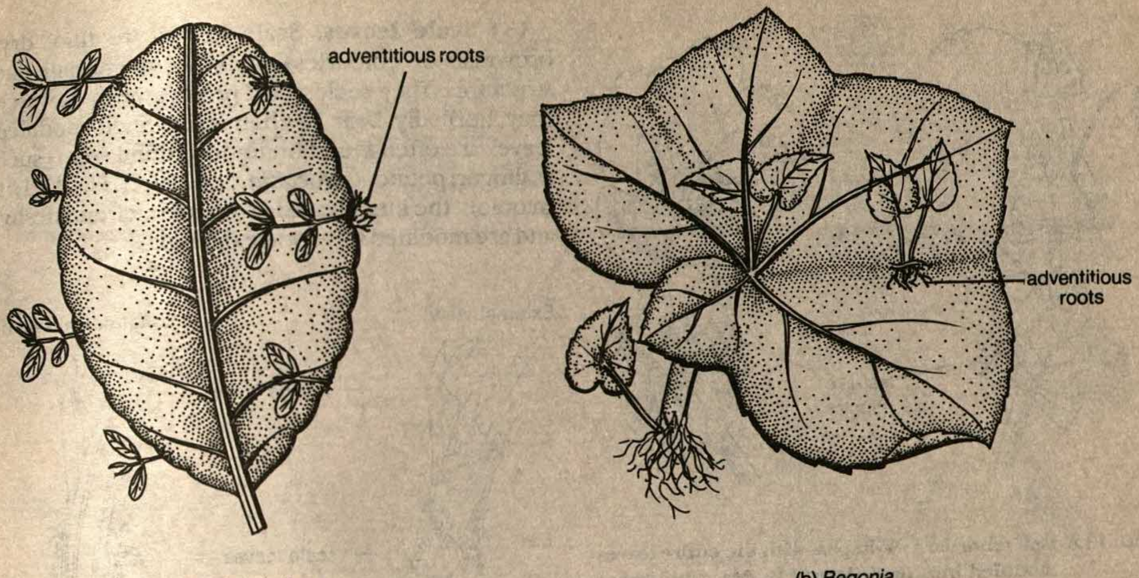
Climbing: In some plants, leaves are wholly or partly modified into tendrils so as to help the plant climb a support. Examples of such leaves are those of *Gloriosa* [Fig. 13.6] and various types of pea plants.

Self-defence and protection: In some plants, leaves are modified into spines or prickles to serve as protective organs against enemies; for instance, grazing animals. Examples of such leaves are those of cacti, date-palm, pineapple [Fig. 13.7], dagger plant, and prickly poppy.

Obtaining nitrogenous food: In some plants, leaves are modified into pitchers or bladders so as to capture insects for obtaining nitrogenous food. Examples of such leaves are those of pitcher plant and bladderwort.

MODIFICATIONS OF LEAVES

We now describe six major modifications of leaves that commonly take place.



(a) *Bryophyllum*

(b) *Begonia*

FIG. 13.5 Foliar buds and adventitious roots

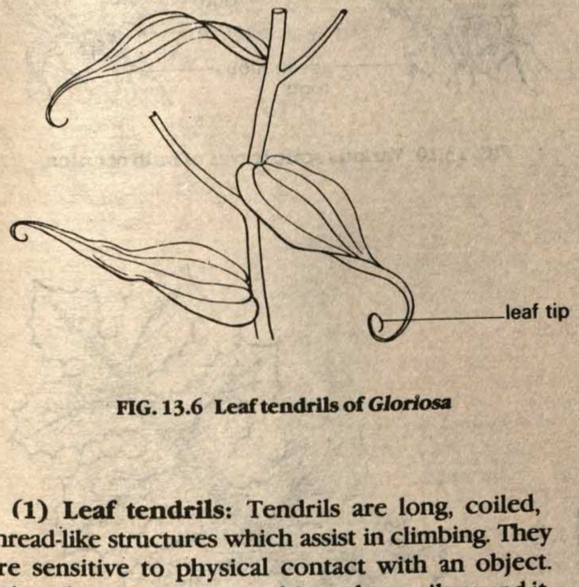


FIG. 13.6 Leaf tendrils of *Gloriosa*

(1) Leaf tendrils: Tendrils are long, coiled, thread-like structures which assist in climbing. They are sensitive to physical contact with an object. When they encounter an object, they coil around it, if possible, and thus grasp it for support. A growing plant can climb up an object, say, a pillar, using its tendrils. Leaves are similarly modified in some cases: In ***Lathyrus aphaca*** (wild pea), the entire leaf is modified into a tendril, while in ***Pisum sativum*** (edible pea) only the terminal leaflets are modified into tendrils [Fig. 13.8]. In garden *Nasturtium*, the petiole is modified into a tendril.

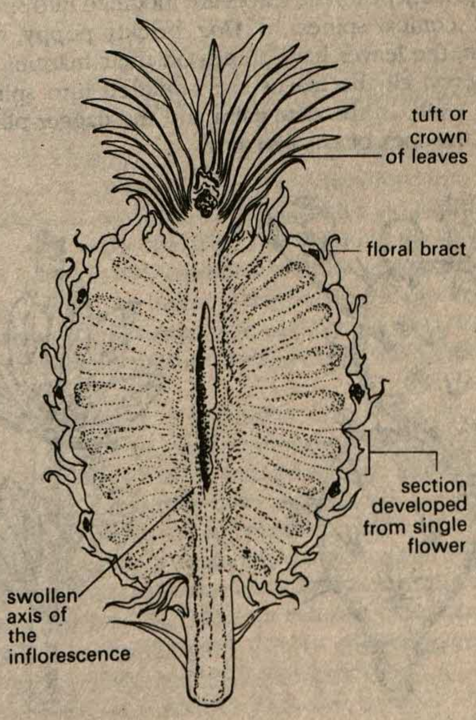


FIG. 13.7 Longitudinal section through pineapple showing spiny leaves at top of fruit

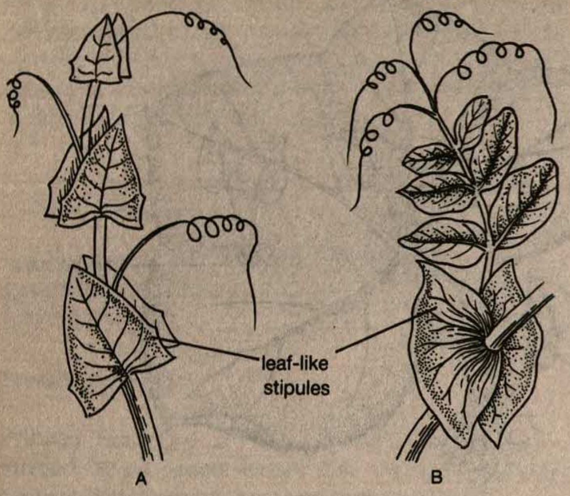


FIG. 13.8 Leaf tendrils: A: Wild pea, with the entire leaves modified into tendrils and B: Pea, with upper leaflets modified into tendrils

(2) Leaf spines: These are sharply pointed structures used for self-defence by a plant. In *Opuntia* (prickly pear) the leaves are modified into small, hard, conical spines. In *Aloe*, prickly poppy, and so on, the leaves have spines on their margins. In barberry, all the leaves are modified into spines [Fig. 13.9]. In the date-palm and the dagger plant, only the apex of a leaf is spiny.

(3) Scale leaves: Scale leaves are thin, dry, brownish or colourless, stalkless, membrane-like structures. They enclose and protect the buds which they normally bear in their axils. Such modified leaves are often found on underground stems such as ginger, potato, *Colocasia*, and onion [Fig. 13.10]. In onion, the inner scale leaves are thick and fleshy, and are modified for storage of food.

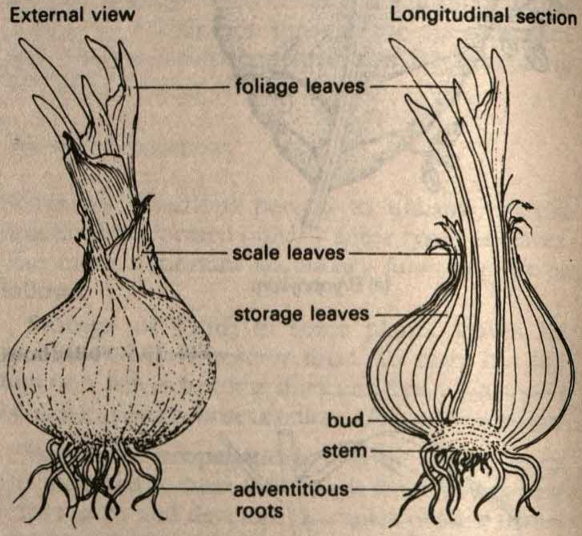


FIG. 13.10 Various scale leaves of bulb of onion

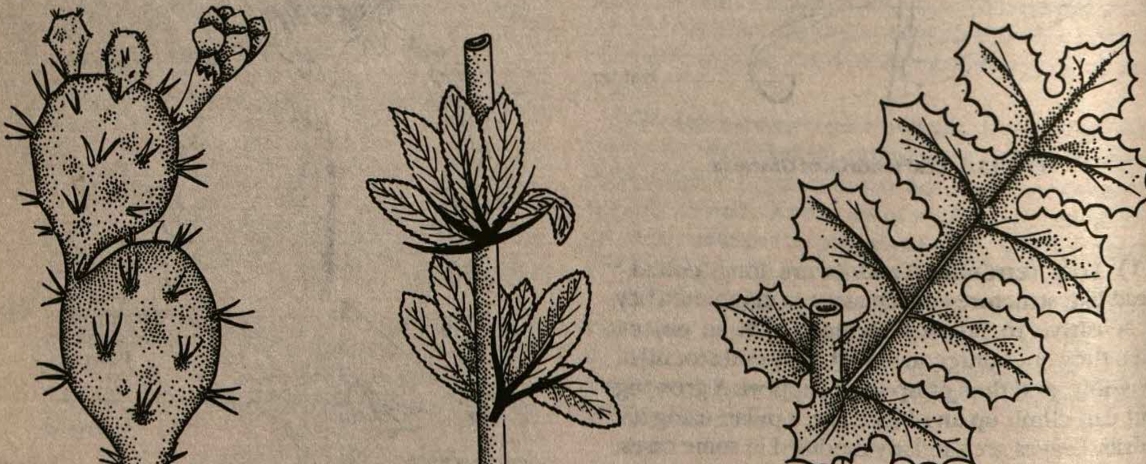


FIG. 13.9 Leaf spines: A: Prickly pear; B: Barberry; and C: Prickly poppy

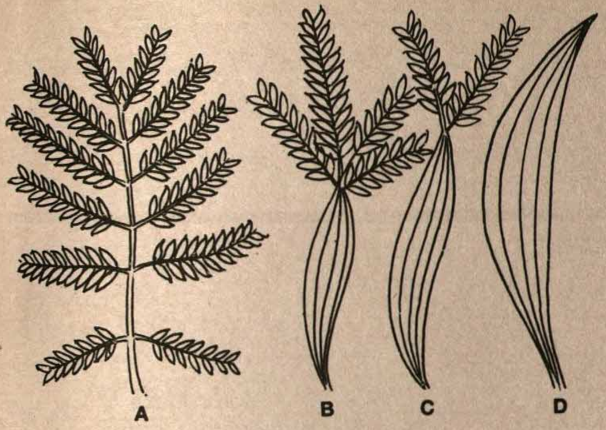


FIG. 13.11 **Development of phyllode in Australian *Acacia*: A: Compound leaf; B-C: Petiole developing into phyllode; D: Phyllode**

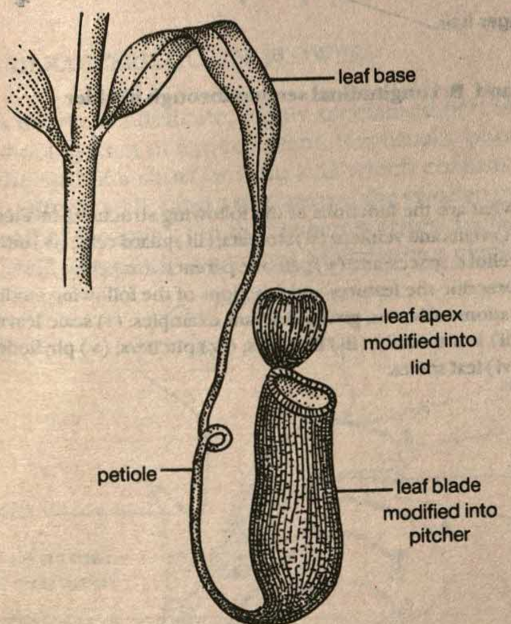


FIG. 13.12 ***Nepenthes khasiana*—a single leaf modified into a pitcher**

(4) Phyllodes: In Australian *Acacia* [Fig. 13.11] the petiole or any other part of the rachis of its compound leaf becomes flattened or winged. It takes the shape of a leaf and turns green in colour. The flattened petiole or rachis is called a **phyllode**. It contains chloroplasts and manufactures food for the plant.

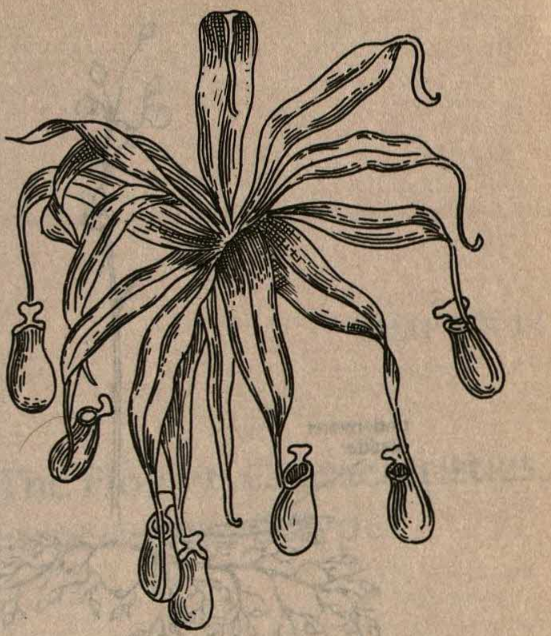


FIG. 13.13 ***Nepenthes khasiana*—an entire plant with pitchers**

(5) Pitchers: In *Nepenthes khasiana* (pitcher plant) the leaf blade or lamina is modified into a **sac (pitcher)**, which is covered with a lid formed by the apex of the leaf [Fig. 13.12]. Along the edges of the opening of the pitcher are placed small **hooks** [Fig. 13.13]. An insect is trapped in the pitcher and digested by the secretion of enzymes into the sac. The slender structure at its lower end is a modified leaf base.

(6) Bladder: *Utricularia* (bladderwort) [Fig. 13.14] is a water plant commonly found floating on the surfaces of lakes and ponds. The segmented leaves on its underwater branches are modified into small balloon-like bladders. Each bladder is 3 mm to 5 mm in diameter and has a small opening called a **trapdoor** surrounded by several **trigger hairs**. Usually, the trapdoor remains closed and the bladder is compressed due to reduced pressure inside it. When a small aquatic animal (e.g., water flea) touches a trigger hair, the trapdoor opens immediately and water (carrying the prey) fills up the bladder. The prey is digested in the bladder by the secretion of enzymes.

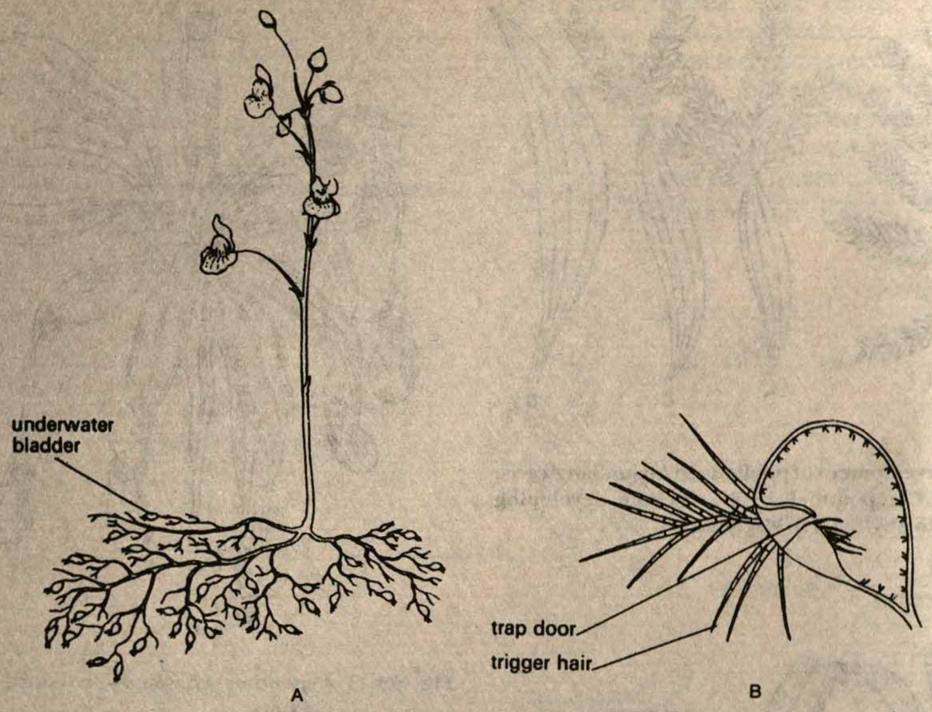


FIG. 13.14 A: *Utricularia*, with underwater bladders and B: Longitudinal section through bladder

EXERCISES

1. List the characteristics by which a leaf can be distinguished from other parts of a plant.
2. Describe in detail all the functions of a leaf.
3. Briefly describe the internal structure of a dorsiventral leaf. How does it differ from that of an isobilateral leaf?
4. What are the functions of the following structures in a leaf? (i) veins and veinlets; (ii) stomata; (iii) guard cells; (iv) intercellular spaces; and (v) palisade parenchyma cells.
5. Describe the features and functions of the following modifications of leaves, giving relevant examples: (i) scale leaves; (ii) leaf tendrils; (iii) bladders; (iv) pitchers; (v) phyllodes; (vi) leaf spines.

CHAPTER 14

The Flower: Characteristics, Structure, and Types

CHARACTERISTICS OF FLOWERS

A flower is a delicate, highly specialised part of the shoot system of a green plant. It is usually borne at the end of a short or long axis which consists of a **pedicel** (stalk) and a **thalamus** (the swollen upper end of the axis). On the thalamus arises the flower itself. A typical flower has four distinct circles or whorls on which its parts are located. Four kinds of parts are found in the flower, namely, **sepals**, **petals**, **stamens**, and **carpels**. These parts are arranged on four circles, called **calyx**, **corolla**, **androecium**, and **gynoecium**. (See Fig. 14.1.)

Sometimes, we find a cluster of flowers located on a single axis. Such a cluster is called an **inflorescence** (Fig. 14.2). In such a case, the pedicel of each flower arises from a common axis. Flowers in an inflorescence are arranged in either an **acro-**

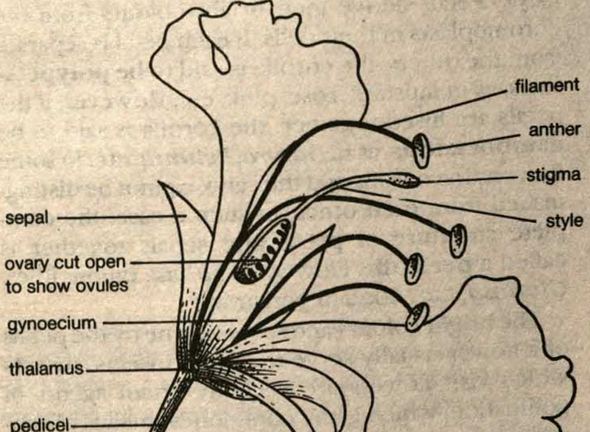


FIG. 14.1 Structure of *Delonix* (gold mohur) flower

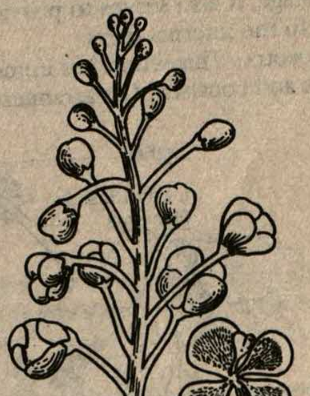


FIG. 14.2 Inflorescence of a dwarf gold mohur

petal order, that is, the lower or outer flowers being older than the upper or inner ones, or a **basipetal order**, that is, the terminal flower being the oldest.

In some instances, we find a single flower or an inflorescence located in the axil of a special leaf; such a leaf is called a **bract**. In other cases, we find a scaly or leafy structure growing on the pedicel of a flower; such a scale or leaf is called a **bracteole**.

STRUCTURE OF FLOWERS

A typical flower consists of four kinds of parts called sepals, petals, stamens, and carpels. These are arranged on four distinct circles or whorls called calyx, corolla, **androecium**, and gynoecium, respectively.

(i) CALYX: This is the outermost whorl of the flower and consists of an arrangement of **sepals**. Sepals are generally green in colour since they contain chloroplasts in their cells and manufacture food for the plant. Sometimes, they contain other plastids (chloroplasts) and have a colour similar to that of the petals; such coloured sepals are called **petaloid sepals**. If each sepal is separate from the others, the calyx is said to be **polysepalous**, as in mustard and radish. However, if the sepals are fused together, the calyx is said to be **gamosepalous**, as in *Hibiscus* (China rose). In flowers like *Hibiscus*, there is an additional whorl of small leaf-like structures called bracteoles located below and outside the calyx; this whorl is called the **epicalyx**.

At the bud stage, the calyx serves to protect the new, delicate inner parts of the flower. At the mature stage, it also serves to provide mechanical support to the internal parts.

(ii) COROLLA: This whorl lies immediately inside the calyx and consists of an arrangement of **petals**; it is fixed on the thalamus at a higher level than the calyx. Petals derive their bright colours from the chromoplasts in their cells. If each petal is separate from the others, the corolla is said to be **polypetalous**, as in mustard, rose, pink, etc. However, if the petals are fused together, the corolla is said to be **gamopetalous**, as in *Datura*, *Petunia*, etc. In some flowers, the corolla and the calyx cannot be distinguished from each other; in such a case, the complete structure of petals and sepals together is called a **perianth.** Flowers of *Salvia*, onion, lilies, *Gloriosa*, etc., contain perianths.

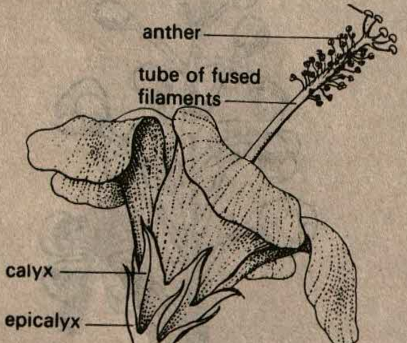


FIG. 14.3 Calyx and epicalyx of *Hibiscus*

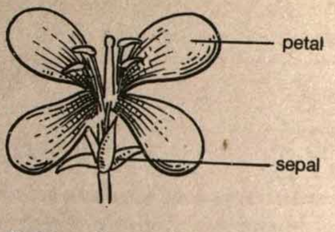


FIG. 14.4(a) Polysepalous calyx and polypetalous corolla of mustard

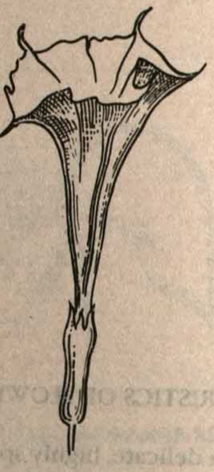


FIG. 14.4(b) Gamosepalous calyx and gamopetalous corolla of *Datura*

The bright colours and scents borne by the petals of a flower usually serve to attract insects. Insects which visit flowers are very important agents of pollination, which is the commonest means of reproduction for flowering plants.

(iii) ANDROECIUM: This whorl lies just within the corolla and consists of an arrangement of the **male** reproductive organs of the flower, which are called **stamens**. The androecium serves as the male reproductive system in the flower. Usually, the stamens arise from the thalamus, but, in some flowers

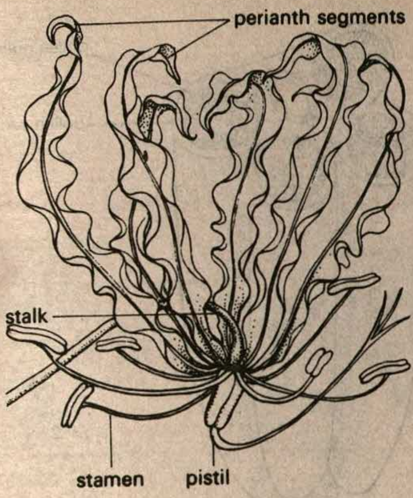


FIG. 14.5(a) Perianth of *Gloriosa*

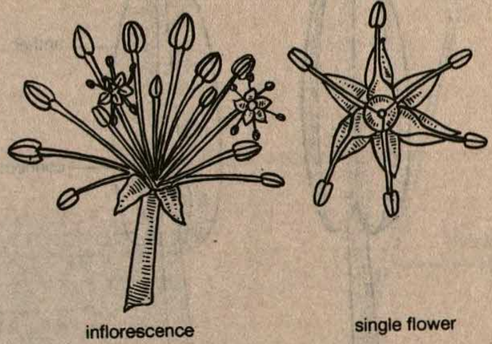


FIG. 14.5(b) Perianth of onion

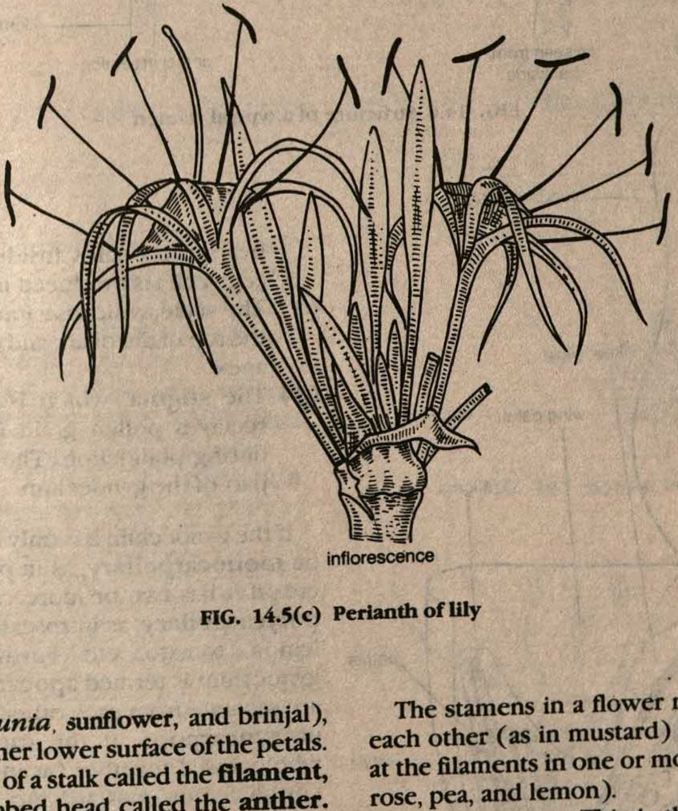


FIG. 14.5(c) Perianth of lily

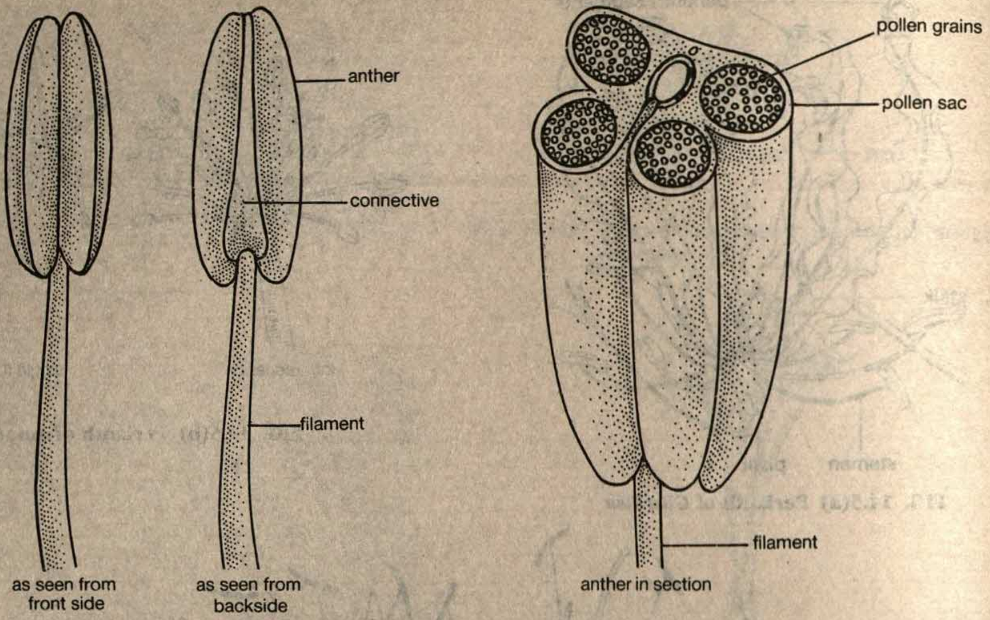
(like China rose, *Petunia*, sunflower, and brinjal), they arise from the inner lower surface of the petals. Each stamen consists of a stalk called the **filament,** which bears a two-lobed head called the **anther.** The anther is usually made up of two swellings called **anther lobes**, which are joined by a connective and each of which contains two **pollen sacs.** A huge number of yellow, dust-like particles called **pollen grains** are produced within each pollen sac. Male **gametes** (sex cells) are produced in each pollen grain.

The stamens in a flower may be separated from each other (as in mustard) or they may be joined at the filaments in one or more groups (as in China rose, pea, and lemon).

(iv) GYNOECIUM: This is the innermost whorl of the flower and is also called the **pistil**. The gynoecium acts as the female reproductive organ of the flower. It is located at the centre of the thalamus and consists of one or more **carpels**.

A carpel is made up of three parts:

(1) The **ovary**, which is the lowermost part and



as seen from front side

as seen from backside

anther in section

FIG. 14.6 Structure of a typical stamen

bears the ovules inside it. A female gamete (egg cell) is produced in each ovule.

(2) The **style**, which is a long stalk that arises from the top of the ovary and carries the stigma at its apex.

(3) The **stigma**, which is a sticky surface that receives pollen grain from the androecium during pollination. The stigma is the highest part of the gynoecium.

If the gynoecium has only one carpel, it is said to be **monocarpellary**, as in pea, bean, gold mohur, etc.; if it has two or more carpels, it is said to be **polycarpellary**, as in rose, lotus, mustard, cotton, lemon, tomato, etc. Further, a polycarpellary gynoecium is termed **apocarpous**, if all its carpels are separate from each other (as in lotus and rose), or **syncarpous**, if the carpels are partially or wholly fused together (as in tomato, lady's finger, cotton, lemon, mustard, etc.

It should be noted that the gynoecium and the androecium are considered to be the **essential parts** of a flower since they are solely responsible for the mechanism of reproduction. On the other hand, the calyx and corolla are considered to be **accessory parts** since they are not directly responsible for the mechanism of reproduction.

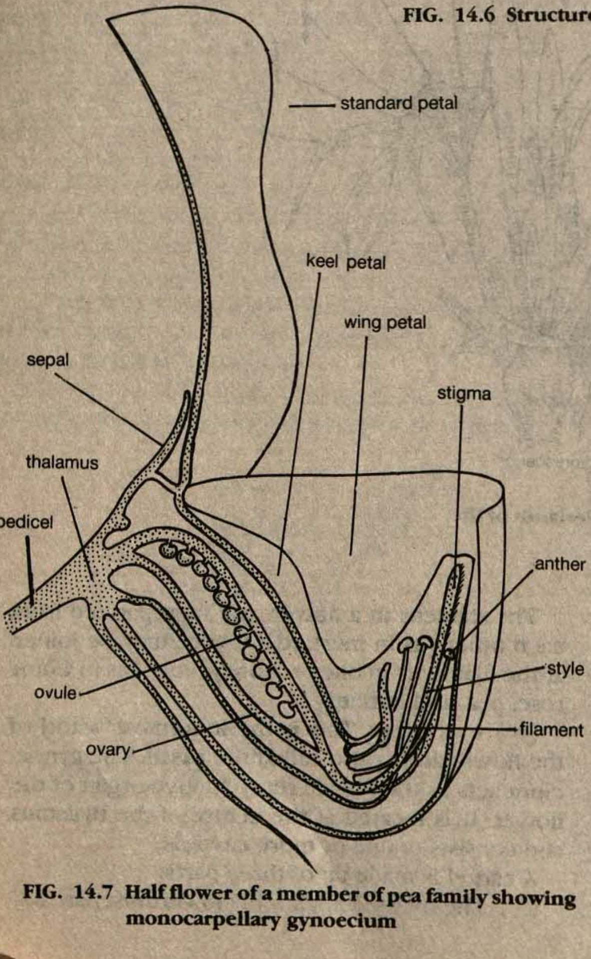


FIG. 14.7 Half flower of a member of pea family showing monocarpellary gynoecium

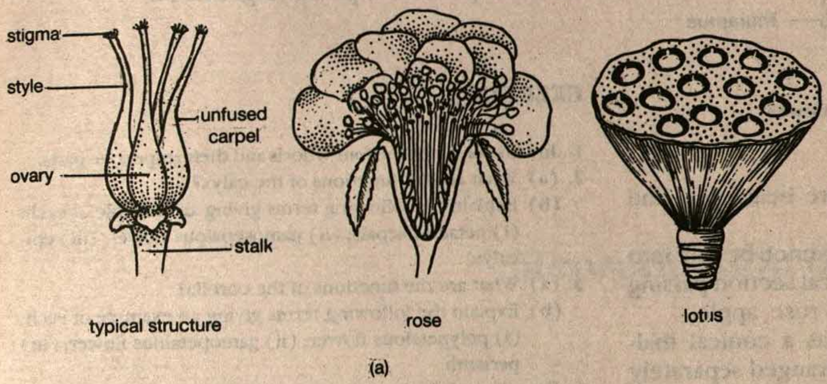


FIG. 14.8(a) Apocarpous gynoecium

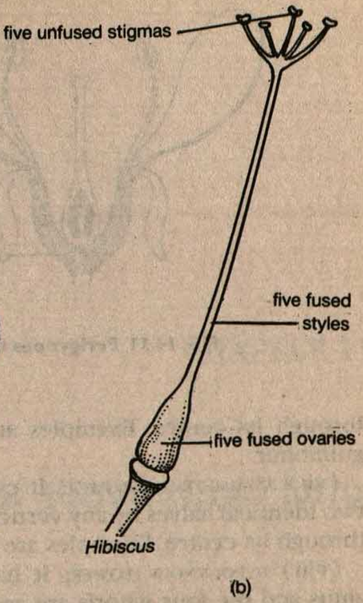


FIG. 14.8(b) Syncarpous gynoecium

DIFFERENT TYPES OF FLOWERS

It should be borne in mind that every type of flower in the plant kingdom does not possess the above-mentioned characteristics and structure. In fact, variations occur and several descriptive terms are used to differentiate them. For instance:

(i) COMPLETE FLOWER: It has all the four whorls: calyx, corolla, androecium, and gynoecium. Examples are mustard, sweet pea, and tomato.

(ii) BISEXUAL FLOWER: It has both the androecium and gynoecium. Examples are apple, gulmohur, mustard, sweet pea, *Petunia*, and tomato.

(iii) UNISEXUAL FLOWER: It has either the androecium or the gynoecium, never both. If it has only the androecium, it is a **male** flower and if it has only the gynoecium, it is a **female** flower. Examples are gourds, papaya and maize. In both these cases, separate male and female flowers grow on the same plant.

(iv) NEUTER FLOWER: It has neither the androecium nor the gynoecium. Examples are the ray florets (a great number of small flowers) in the inflorescence of a sunflower.

(v) SYMMETRICAL FLOWER: Such a flower can be cut into two identical halves by any vertical section passing through its centre. Examples are mustard, brinjal, and tomato. This type of flower is also called **actinomorphic**.

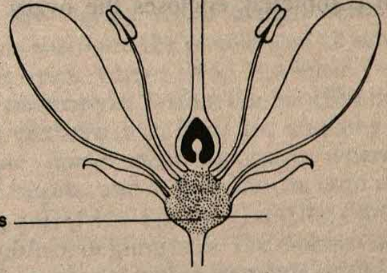


FIG. 14.9 Hypogynous flower

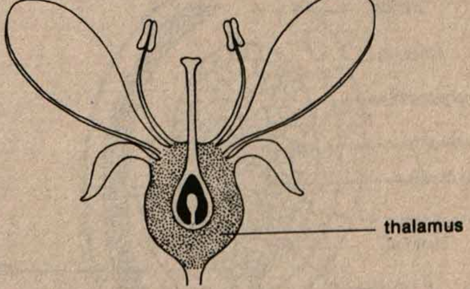


FIG. 14.10 Epigynous flower

(vi) MONOSYMMETRICAL FLOWER: Such a flower (also called a **zygomorphic** flower) can be cut into two identical halves by one particular vertical section

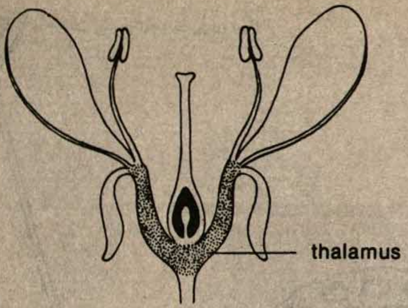


FIG 14.11 Perigynous flower

through its centre. Examples are bean, pea, and gulmohur.

(vii) ASYMMETRICAL FLOWER: It cannot be cut into two identical halves by any vertical section passing through its centre. Examples are rose, apple.

(viii) HYPOGYNOUS FLOWER: It has a conical thalamus and the four whorls are arranged separately on the thalamus. The gynoecium is uppermost and is said to be 'superior'. Examples are mustard, China rose, and brinjal.

(ix) EPIGYNOUS FLOWER: It has a cup-like thalamus which completely encloses the ovary. Thus, the ovary is at the bottom and is said to be 'inferior'. In such a flower, the sepals, petals, and stamens are located on top of the thalamus. Examples are guava, sunflower, apple, pear, and cucumber (Fig. 14.10).

(x) PERIGYNOUS FLOWER: It has a cup-like thalamus which encloses the ovary, but the sepals, petals, and stamens arise from the edge of this cup. Examples are rose, plum, and peach (Fig. 14.11).

EXERCISES

1. In a flower, name the four whorls and their respective parts.
2. (a) What are the functions of the calyx?
   (b) Explain the following terms giving an example of each: (i) petaloid sepals; (ii) gamosepalous flower; (iii) epicalyx.
3 (a) What are the functions of the corolla?
   (b) Explain the following terms giving an example of each: (i) polypetalous flower; (ii) gamopetalous flower; (iii) perianth.
4. Describe, with the aid of simple and neat diagrams, the structure of (i) the androecium and (ii) the gynoecium.
5. Explain the following terms with two examples of each: (i) regular flower; (ii) hypogynous flower; (iii) incomplete bisexual; (iv) polycarpellary syncarpous flower; and (v) perigynous flower.

CHAPTER 15

Reproduction of Flowering Plants

In the previous chapter, we learnt that a typical flower possesses both male and female reproductive systems. The male **gametes** (sex cells) are produced in the **pollen grains** found in the anther and the female gametes in the **ovules** found in the ovaries. Pollen grains are transferred from the anther to the stigma by a process called **pollination**; after pollination, a male gamete and a female gamete fuse together within an ovule during the process of **fertilisation.** Fertilised ovules grow into seeds. Under favourable conditions, seeds germinate and give rise to seedlings which develop into new, independent plants. The entire process is very complex, and we shall now study its various aspects in detail.

REPRODUCTIVE BODIES

(a) POLLEN GRAINS: These are **male reproductive** bodies formed in the **pollen sacs** of an anther on a stamen. A pollen grain measures 10 to 200 microns in diameter. It is a two-walled structure: the outer wall is called the **exine** and the inner wall the **intine.** The exine is spiny or warty, whereas the intine is smooth. These walls enclose a microscopic male **gametophyte** which gives rise to two male gametes after pollination has occurred. These two male sex cells are responsible for the fertilisation of an ovule.

(b) OVULES: These are the **female** reproductive bodies formed in the ovary at the bottom of the carpel. Each ovule is attached to the **placenta** (part of the ovary wall) by a slender stalk called the **funicle.** The funicle conducts food material from the placenta to the ovule. An ovule consists of a mass of tissue called the **nucellus** surrounded by two protective layers called **integuments.** The integuments surround the nucellus on all sides except at the apex, where there is a small passage called the **micropyle.** Within the nucellus lies the large oval **embryo sac.** This sac contains three microscopic nuclei near its apex, where the micropyle begins; one of these nuclei is an unprotected **egg cell** (female gamete) and the other two are **synergids** or helping cells. The embryo sac also contains three nuclei which form **antipodal cells**

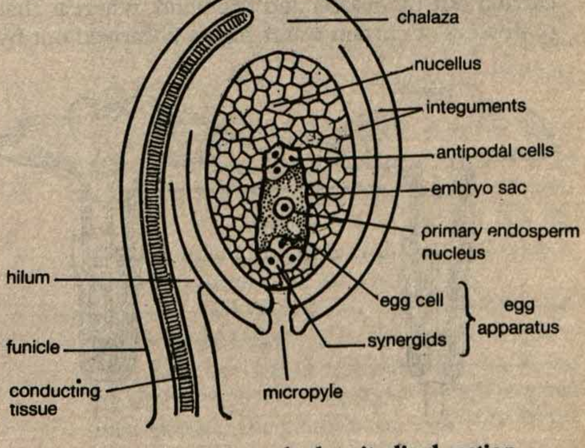


FIG. 15.1 An ovule in the longitudinal section

(which probably feed a young embryo) and a **primary endosperm nucleus.** During the process of fertilisation which follows pollination, the two male gametes enter the ovule through the micropyle; one male gamete fuses with the egg cell to form a **zygote**, while the other fuses with the primary endosperm nucleus to form the **endosperm nucleus** or secondary nucleus which, later on, forms the endosperm. This fusion of one male gamete with the egg cell and the other with the primary endosperm nucleus is called **double fertilisation.**

POLLINATION

As already stated, pollen grains are produced in the anthers (swollen two-lobed heads) of stamens in the androecium of a flower. Various agents (insects, wind, water) transfer some pollen grains from the anthers to the stigma in the gynoecium. If pollen grains from the anthers of one flower are transferred to the stigma of another flower borne on another plant of the same species, the process is called **cross-pollination.** If they are transferred from the anthers of one particular flower to the stigma of the same flower or to the stigma of another flower borne on the same plant, we have **self-pollination**. Pollination is very important since it transports the male reproductive bodies to the gynoecium of the flower and hence paves the way for fertilisation.

AGENTS OF POLLINATION

Pollination of flowers of land plants is usually carried out by insects and the wind, whereas that of flowers of certain water plants is carried out by water. Thus, insects, wind, and water are considered to be the agents of pollination. We now briefly describe how these agents effect pollination.

(i) **Insects**: Insects visit flowers to feed on their pollen and nectar. The nectar of a flower is produced in the **nectary**, which is a gland situated well within the flower. When the insect reaches for the nectary, some parts of its body come into contact with the anthers. Pollen grains are thus transferred to the body parts of the insect. When the same insect visits another flower, some of the pollen grains from its body are transferred to the stigma of the second flower, due to contact, while the insect is feeding on its nectar. Thus, pollination is accidentally effected by insects. Examples of insect-pollinated flowers are those of sweet pea and *Salvia.*

Let us now examine why insects are drawn towards flowers and how different parts of both the insect and the flower facilitate pollination.

Flowers have certain characteristics with which they attract insects. Some of these characteristics are as follows:

(1) Flowers are often large and showy, and this attracts insects. Some small flowers are arranged in large inflorescences, which creates the same degree of attraction.

(2) Usually, petals possess bright and attractive colours. It is believed that several types of insects can distinguish one colour from another.

(3) Usually, flowers carry a fragrance which entices insects.

(4) Flowers produce nectar, a thick sugary fluid, on which insects like to feed.

Flowers have other characteristics too which help them effect pollination by means of insects. These characteristics are as follows:

(1) Pollen grains are produced in small quantities

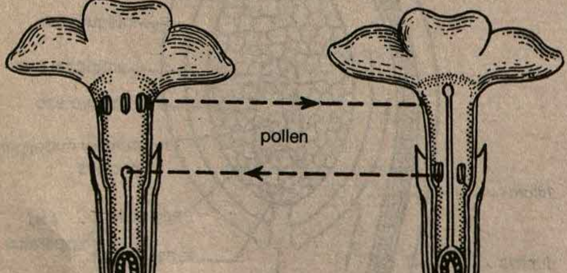


FIG. 15.2 Cross-pollination in a primrose

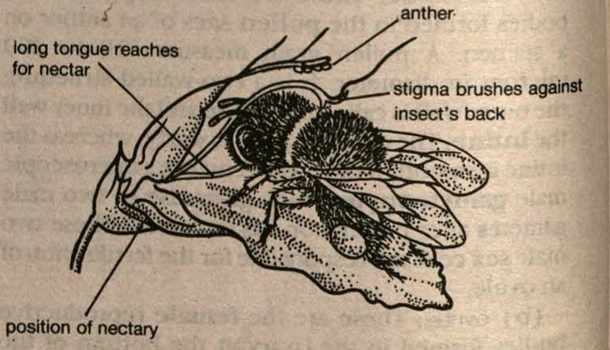

anther
long tongue reaches for nectar
stigma brushes against insect's back
position of nectary

FIG. 15.3 Insect pollination

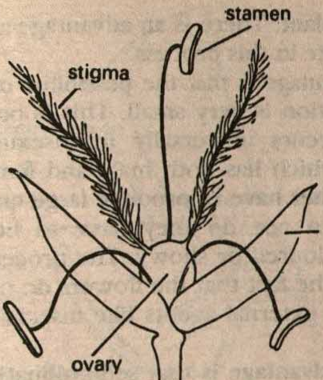


FIG. 15.4 A bisexual grass flower pollinated by wind

but they are relatively large and have a rough and/or sticky outer surface which helps them to stick to the body parts of the insects visiting the flower.

(2) Flowers have a stigma which is small and rigid and is covered with a very sticky material. When the body parts of a visiting insect rub against the stigma, any pollen grains they may be carrying get caught easily in this sticky material. This enables pollination to occur.

(3) Often flowers are shaped so that insects may obtain nectar from them easily. Usually, the nectary is located in such a place that the body parts of a visiting insect must necessarily rub against the reproductive parts of the flower. Some flowers are shaped in such a way that only certain insects can suck their nectar. Thus, only such insects can bring about pollination.

(ii) **Wind**: In some cases, the wind serves to carry pollen grains from the anthers of one flower to the stigma of another and, hence, brings about cross-pollination. Such flowers are known as **anemophilous flowers.** Examples of such flowers are grass, maize, cereals, and pines.

Flowers pollinated by the wind possess certain characteristics, some of which are as follows:

(1) Flowers which are small and not very noticeable do not attract insects. Such flowers are often pollinated by the wind.

(2) Flowers which do not produce nectar are also pollinated by the wind.

(3) Flowers which are not brightly coloured and fragrant are also pollinated by the wind.

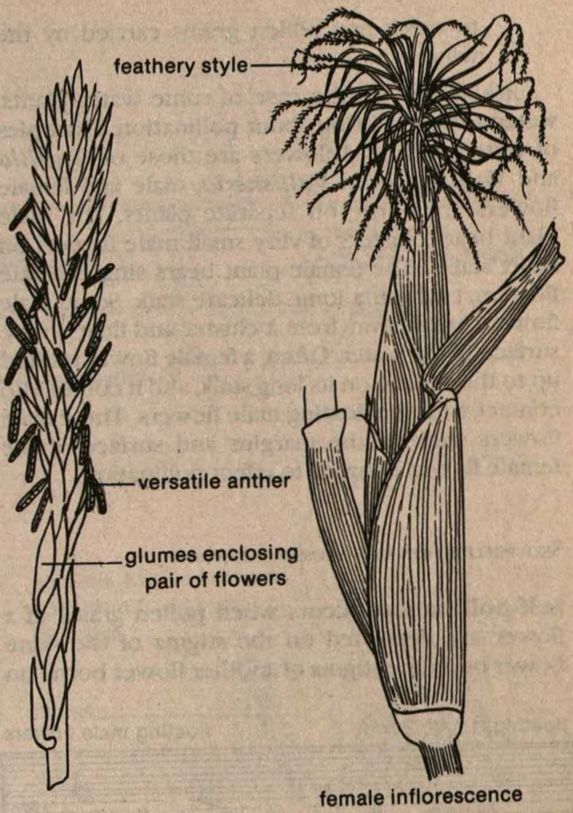


FIG. 15.5 Maize—a wind-pollinated plant

(4) Sometimes, flowers which cannot attract insects produce large quantities of pollen grains. These grains are very small, smooth and light and can be easily carried by the wind. However, most of the pollen grains are wasted because only a few of them can find their way to the stigmas of other flowers (when carried by the wind) and the rest are scattered.

(5) Stamens of wind-pollinated flowers have hinged (versatile) anthers placed on long and flexible filaments which extend well outside the corolla for exposure to air currents. This makes it easier for pollen grains to be carried off by the wind.

(6) Stigmas of wind-pollinated flowers are long, flexible and feathery (having a large surface area for receiving the pollen grains) and are usually placed on long styles which extend well outside the corolla for exposure to air currents. This makes it easier for the stigma

to catch any pollen grains carried by the wind.

(iii) **Water**: In the case of some water plants, water serves to bring about pollination. Examples of water-pollinated flowers are those of *Hydrilla* and *Vallisneria*. In *Vallisneria*, male and female flowers are borne on separate plants. The male plant bears clusters of very small male flowers on short stalks. The female plant bears single female flowers, each on a long, delicate stalk. Some male flowers break away from a cluster and float on the surface of the water. Often, a female flower is lifted up to the surface on its long stalk, and it comes into contact with the floating male flowers. These male flowers stick to the margins and surface of the female flower in order to effect pollination.

SELF-POLLINATION AND CROSS-POLLINATION

Self-pollination occurs when pollen grains of a flower are deposited on the stigma of the same flower or on the stigma of another flower borne on the same plant. There is an advantage as well as a disadvantage in this process.

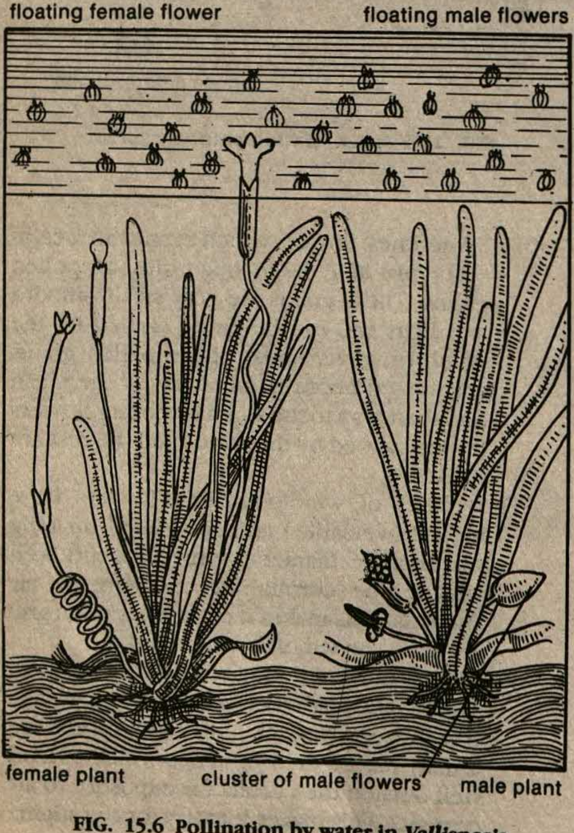


FIG. 15.6 Pollination by water in *Vallisneria*

The advantage is that the possibility of failure in self-pollination is very small. This is because this process occurs universally in bisexual flowers (each of which has both male and female parts) which neither have to produce large quantities of pollen grain nor do they have to be fragrant, brightly coloured or showy. The process is made secure by the fact that the flowers do not have to depend on external agents like insects, wind and water.

The disadvantage is that self-pollination occurs for several generations consecutively, the offspring becoming weaker each time. This happens because the characters of the same plant are inherited each time reproduction occurs. Further, chances of variation in the offspring and improvement in the new generation are not so frequent.

Cross-pollination occurs when the pollen grains of one flower are deposited on the stigma of another flower borne on another plant of the same species. There are several advantages and disadvantages in this process also.

The advantages are that cross-pollination produces better results than self-pollination: offspring are healthier; new varieties better adapted to the environment are produced; and a large number of seeds are produced in fruits. All these improvements are due to the mixed paternal and maternal characters of two different plants of the same species.

The disadvantages are that cross-pollination depends on external agents like insects, wind, and water, which are not fully effective at all times. Also, there is considerable wastage of pollen grains, especially in the case of wind-pollinated flowers.

MECHANISMS OF POLLINATION IN SOME FLOWERS

We shall now study in some detail how pollination is effected in some flowering plants. We shall take up two examples (pea and *Salvia*) of insect pollination and one example (Guinea grass) of wind pollination.

(i) **Pea**: The flower of the pea is large and zygomorphic. Its petals are scented and brightly coloured (red, purple, white, etc.), being characteristic of an insect-pollinated flower.

The calyx is **gamosepalous**, consisting of five fused green sepals. The sepals are much smaller than the petals. The corolla also has five petals:

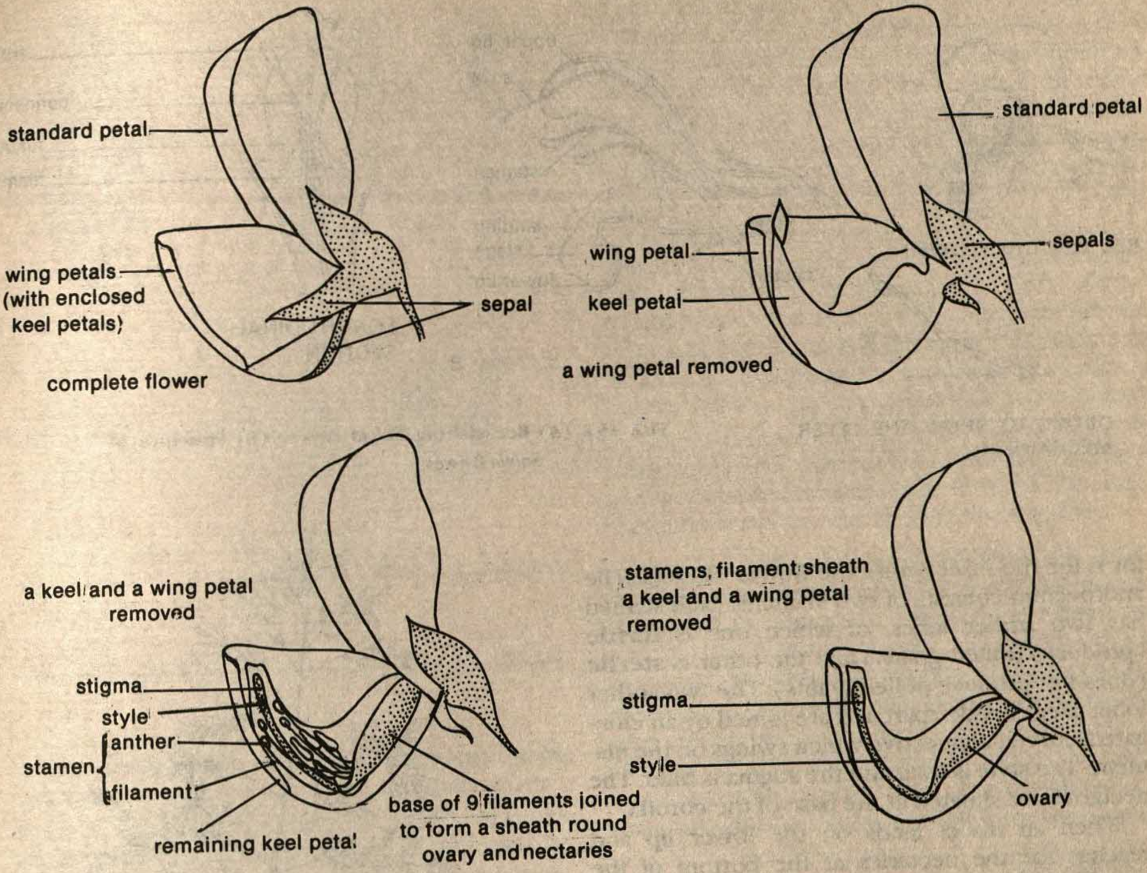
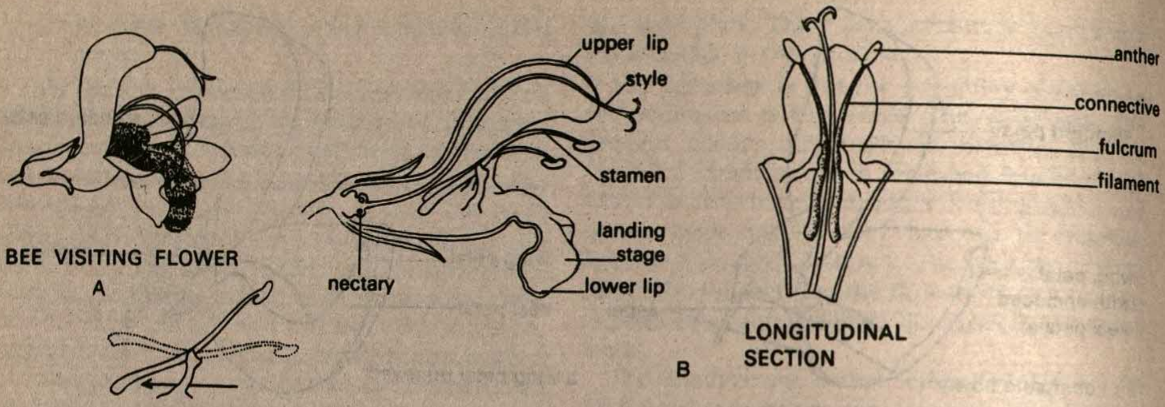


FIG. 15.7 Structure of a flower of pea family

there are two fused **keel petals** below (enclosing the androecium and gynoecium), two free lateral **wing petals**, and one large **standard petal** above. The androecium consists of ten stamens: nine of which are fused at the base and enclose the nectaries and the ovary, while the tenth one is free and is placed higher. The gynoecium consists of a single carpel containing several ovules.

Heavy insects like the bumble bee are attracted by the scent and the colours of the pea flower. The insect lands on the wing petals on the side, which are lowered due to the weight of the insect's body. The insect pushes in its long tongue in search of nectar. The wing petals are connected to the keel petals by ridges on their inner surfaces, so that the keel petals are also pressed down. This causes the inner sexual organs of the flower to be exposed. In the flowers of the pea, anthers mature earlier and the pollen grains are shed at a time when its stigma is not mature to receive its pollen grains. When an insect visits a younger flower, where anthers are mature, pollen grains are dusted against its under surface. When the same insect visits an older flower, where the stigma is mature, the pollen grains may be brushed off its body on to the mature stigma to effect pollination incidentally. If pollination by insects fails, self-pollination may take place since the androecium and gynoecium are enclosed within the keel.

(ii) **Salvia**: The flower of *Salvia* is also zygomorphic. It bears a perianth. Its calyx is gamosepalous, consisting of three united sepals which are brightly coloured like the petals (petaloid perianth). Its brightly coloured gamopetalous corolla forms two lips: the **upper lip** consists of two fused petals and forms a hood that covers the androecium and the gynoecium; and the **lower lip** consists of three fused petals and forms a broad landing plat-



DETAIL TO SHOW THE LEVER MECHANISM

FIG. 15.8 (A) Bee visiting *Salvia* flower (B) Structure of *Salvia* flower

form for the insects that the flower attracts. The androecium consists of two stamens: each stamen has two anther lobes, of which one is **fertile** (produces pollen grains) and the other is **sterile** (does not produce pollen grains). The two anther lobes are set wide apart and are joined by an elongated, curved connective which swings on the filament. The style is long and the stigma is bifid. The nectaries are situated at the base of the corolla.

When an insect lands on the lower lip and reaches for the nectaries at the bottom of the **corolla tube**, its body pushes against the sterile anther lobe. This causes the connective to first pull and then swing the fertile anther lobe, which strikes the back of the insect and dusts it with pollen grains. These grains are carried by the insect to another flower.

The flower of *Salvia* is **protandrous** since its male parts (anthers) mature before its female parts (stigma). Because of this characteristic, pollination occurs with a young flower contributing pollen grain to the stigma of an older flower. Thus, each flower contributes pollen grain from the fertile anther lobe when young, and is itself pollinated when it becomes old. As each flower grows older, its style grows longer and bends lower, so that the mature stigma may get dusted with pollen grains from the back of the insect's body (deposited there from the anthers of a younger flower visited by it earlier) as it enters the flower.

(iii) **Guinea grass**: This grass is very commonly grown for fodder. It bears flowers which are neither scented nor brightly coloured, and exhibit the characteristics of wind-pollinated flowers.

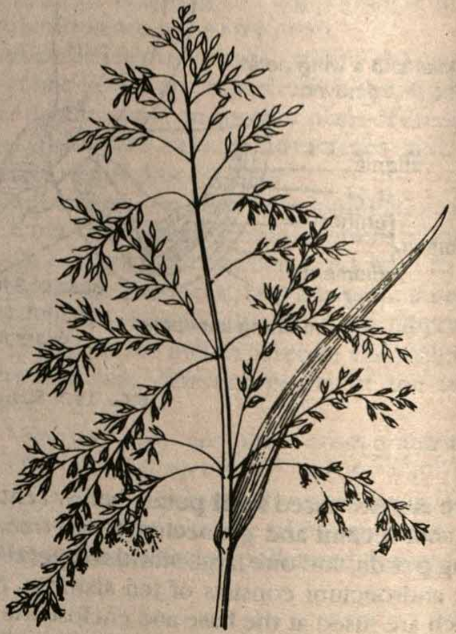


FIG. 15.9 Inflorescence of Guinea grass

The Guinea grass flowers are born in an **inflorescence** which consists of long fine branches bearing the flowers in pairs, the end of each pair of flowers being enclosed in **bracts** to form a **spikelet** 3 to 4 mm long. Inside a spikelet, the **lower flower** consists of only three yellowish stamens, while the **upper flower** consists of three stamens and the pistil with two feathery brownish-purple stigmas. In both the flowers, the calyx and the corolla are modified into two small structures called **lodi-**

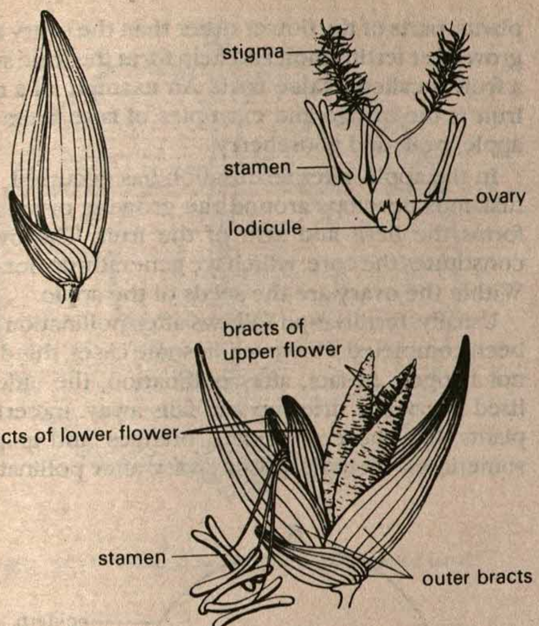


FIG. 15.10 External and internal structure of spikelet

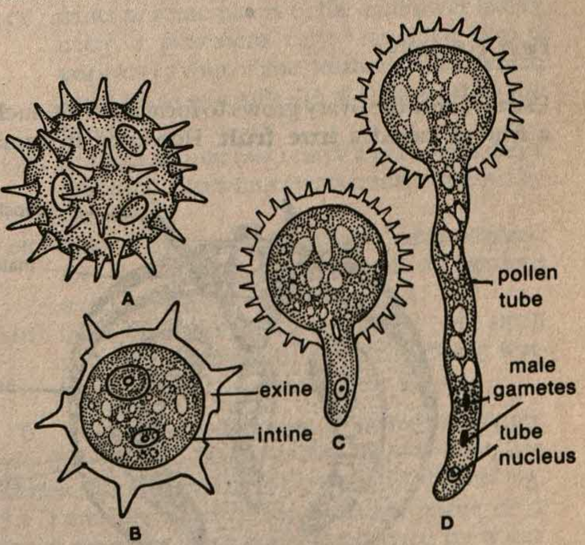
cules. Both the flowers are enclosed by bracts: the two bracts enclosing the upper flower form a wrinkled membranous structure, while the bracts enclosing the lower flower are green and leaf-like.

The flowers of Guinea grass also are protandrous, i.e., their anthers mature before their stigmas. In younger flowers, the stamens project out of the spikelets, while, in older flowers, the stigmas project out. The stamens develop beneath the projective bracts—when they have matured, the bracts open slightly, the filaments lengthen rapidly, and the versatile anthers emerge from the spikelet. The filaments, being in the form of fine threads, are easily shaken by the slightest breeze. When this happens, the anthers burst and spill their pollen grains, which are carried away by the air. Some of these grains fall on the projecting stigmas of older flowers and bring about wind pollination. The large feathery surface of a mature stigma is a good receiving surface for the pollen grains.

FERTILISATION

After pollen grains have been deposited on the stigma, they absorb moisture and sugar from its sticky surface and swell up. The outer wall (**exine**) of a pollen grain is quite thin in some places, and from one particular point, the inner wall (**intine**) begins to bulge out. The intine then grows to form the **pollen tube** which penetrates through the tissues of the stigma and the style towards the ovary at the bottom. On reaching the ovary, the pollen tube makes its way further into an **ovule** through its mircopyle. The tip of the pollen tube carries two **male gametes** in addition to a pollen tube nucleus. This tip enters the embryo sac within the ovule where it dissolves. One of the male gametes then fuses with the egg cell (female sex cell) to form a **zygote.** The other male gamete fuses with the primary endosperm nucleus present in the embryo sac to form the **endosperm nucleus**. This nucleus divides rapidly to form **endosperm tissue**, which, in some cases, serves to store food material for the seed. The fusion of the male gamete and the female gamete is called **fertilisation**. It should be noted that several ovules may be fertilised together.

After fertilisation has occurred, the sepals, petals, stamens, style, and stigma dry up and fall off from the thalamus. (In some cases, as in brinjal and tomato, the dried up sepals may remain on the thalamus.) The fertilised ovules and ovary continue to remain, receiving food from the main plant. They gradually develop into the seeds and the fruit. Inside a fertilised ovule, the zygote divides and grows into the **embryo** of the **seed**. The integuments of the ovule thicken and harden to form **seed coats.**



A — an entire pollen grain
B — a pollen grain in section
C and **D** — germinating pollen grains

FIG. 15.11 Pollen grain—structure and germination

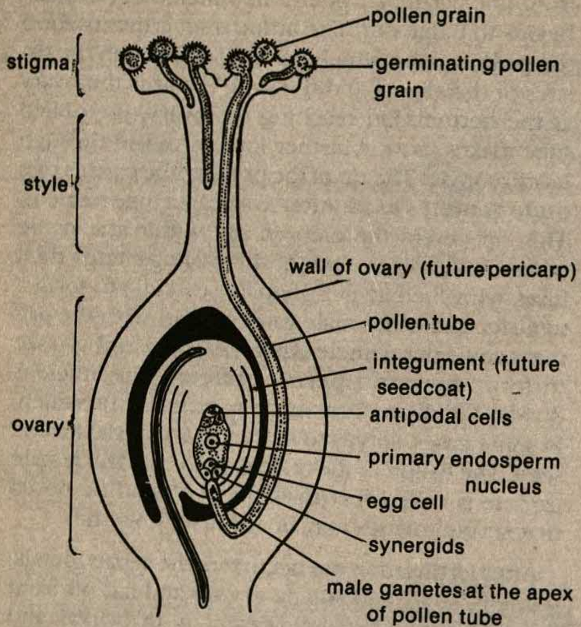

pollen grain
stigma
germinating pollen grain
style
wall of ovary (future pericarp)
pollen tube
integument (future seedcoat)
ovary
antipodal cells
primary endosperm nucleus
egg cell
synergids
male gametes at the apex of pollen tube

FIG. 15.12 Fertilisation in plants

The entire ovary grows to form the **fruit**, and the ovary wall forms the **pericarp** (skin or wall) of the fruit.

FRUIT FORMATION

Usually, only the ovary grows to form the fruit; such a fruit is called a **true fruit**. However, in some plants, parts of the flower other than the ovary also grow after fertilisation and help form the fruit; such a fruit is called a **false fruit**. An example of a true fruit is the mango and examples of false fruits are apple, pear, and gooseberry.

In the apple, after fertilisation has occurred, the thalamus develops around the growing ovary and forms the flesh and skin of the fruit. The ovary constitutes the core, which we generally do not eat. Within the ovary are the seeds of the apple.

Usually, fertilisation follows after pollination has been completed. However, in some cases, this does not happen. In fact, after pollination, the unfertilised ovary just dries up and falls away. In certain plants, like those of banana, oranges, and grapes, sometimes, the unfertilised ovary after pollination

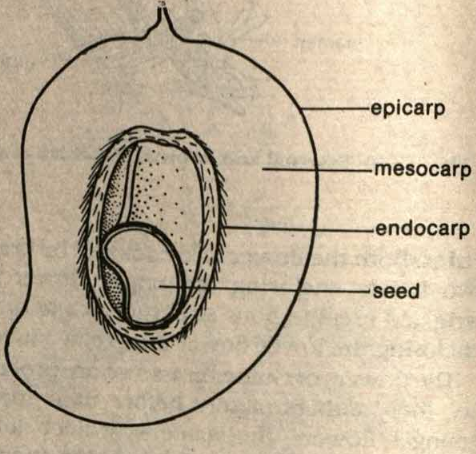
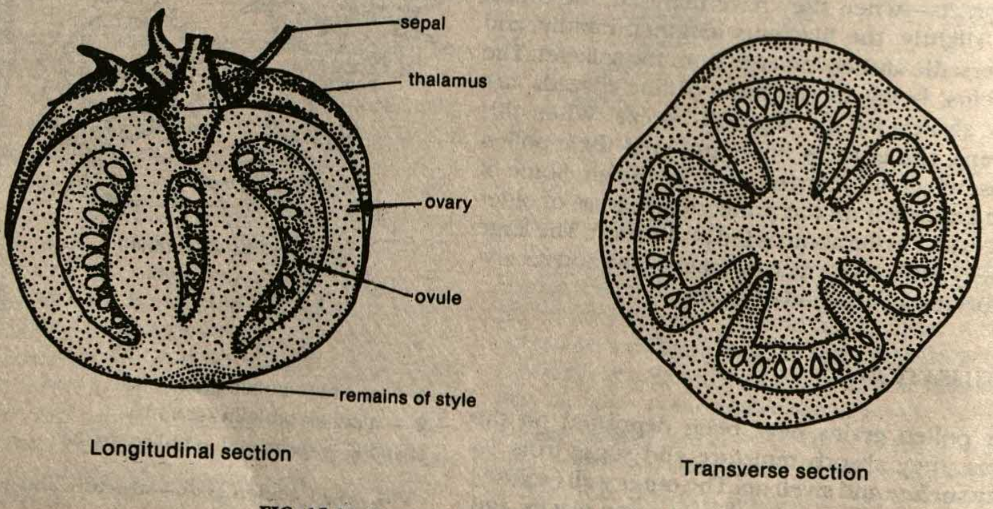


FIG. 15.14 Structure of mango, a true fruit



Longitudinal section

Transverse section

FIG. 15.13 Formation of fruit in tomato

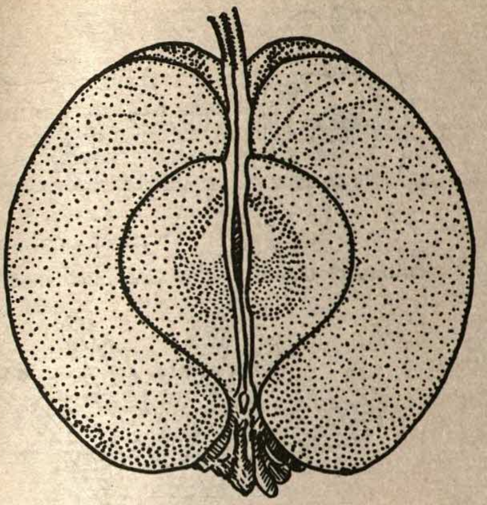


FIG. 15.15 Vertical section of apple, a false fruit

does not fall off but grows into a fruit. A fruit which grows from an unfertilised ovary is called a **parthenocarpic fruit**; it does not contain seeds since the ovules in the ovary cannot form seeds without fertilisation. Fruits such as bananas and seedless grapes, guavas, oranges, and lemons are extremely popular with consumers since they are easy to digest, and plant breeders all over the world are trying to induce parthenocarpy in an increasing variety of fruits.

DISPERSAL OF FRUITS AND SEEDS

A seed contains the **embryo** of a new plant. If the fruits and seeds formed on a plant fall at its base and the seeds find their way into the soil there, new plants take root very close to the parent plant. These offspring tend to be crowded together and compete with one another for natural resources such as light, air, water, and mineral salts. Such competition does not permit them to grow normally. In order that seeds acquire favourable conditions for **germination**, survival, and growth, Nature has evolved several means of scattering fruits and seeds away from the parent plant and other nearby plants. The scattering of fruits and seeds to enable plants to lead a proper life is called **dispersal**.

In some plants, only seeds are dispersed, while in others, fruits (with the seeds inside them) are also dispersed. Fruits and seeds may be adapted or modified to suit methods of dispersal. The various agents of dispersal include wind, water, animals (including birds), explosive mechanisms in plants, and human beings. We shall now describe how these agents enable seeds to reach places which offer conditions suitable for germination and new life.

(a) **Wind**: The wind disperses or scatters those fruits and seeds which are very small and light. Some seeds are provided with hairs or membranous, wing-like structures which enable them to be carried away easily. Examples of seeds and fruits easily dispersed by the wind are [Fig. 15.16]:

(i) seeds of the orchid, which are very light and small;

(ii) seeds of *Calotropis*, cotton, etc., which are provided with a thick coating of fine, silky hairs;

(iii) seeds of *Moringa* (drumstick), *Oroxylon*, *Cinchona* and *Jacranda* have their **testa** (outer seed coat) modified into one or more flat, wing-like structures (to aid dispersal by the wind);

(iv) seeds of the poppy, being small, are contained in a **capsule** (fruit) at the end of a long stalk and are shaken out through the pores of the capsule by the wind; this is called the **censer mechanism**;

(v) fruits of some plants of the sunflower family carry a persistent calyx modified into a **pappus** (a ring of fine, feathery hairs) which acts like a parachute (to aid dispersal by the wind);

(vi) fruits of *Shorea* (sal) carry a persistent calyx modified into wings (which aids dispersal by the wind);

(vii) fruits of *Sycamore*, *Dioscorea* (yam), *Hiptage*, etc., have the **pericarp** (wall of matured ovary) modified into wings; and

(viii) fruits of *Clematis*, *Naravelia*, etc., are small and carry persistent styles which are feathery (and aid dispersal by the wind).

(b) **Water**: Fruits dispersed by water have outer coats that are modified to enable them to float. For example, the **mesocarp** of a coconut is fibrous [Fig. 15.17] and the fruits of the lotus are borne on a spongy thalamus. Such fruits are carried by water currents over long distances without suffering injury during dispersal.

(c) **Animals and human beings:** Animals and human beings are important agents of dispersal

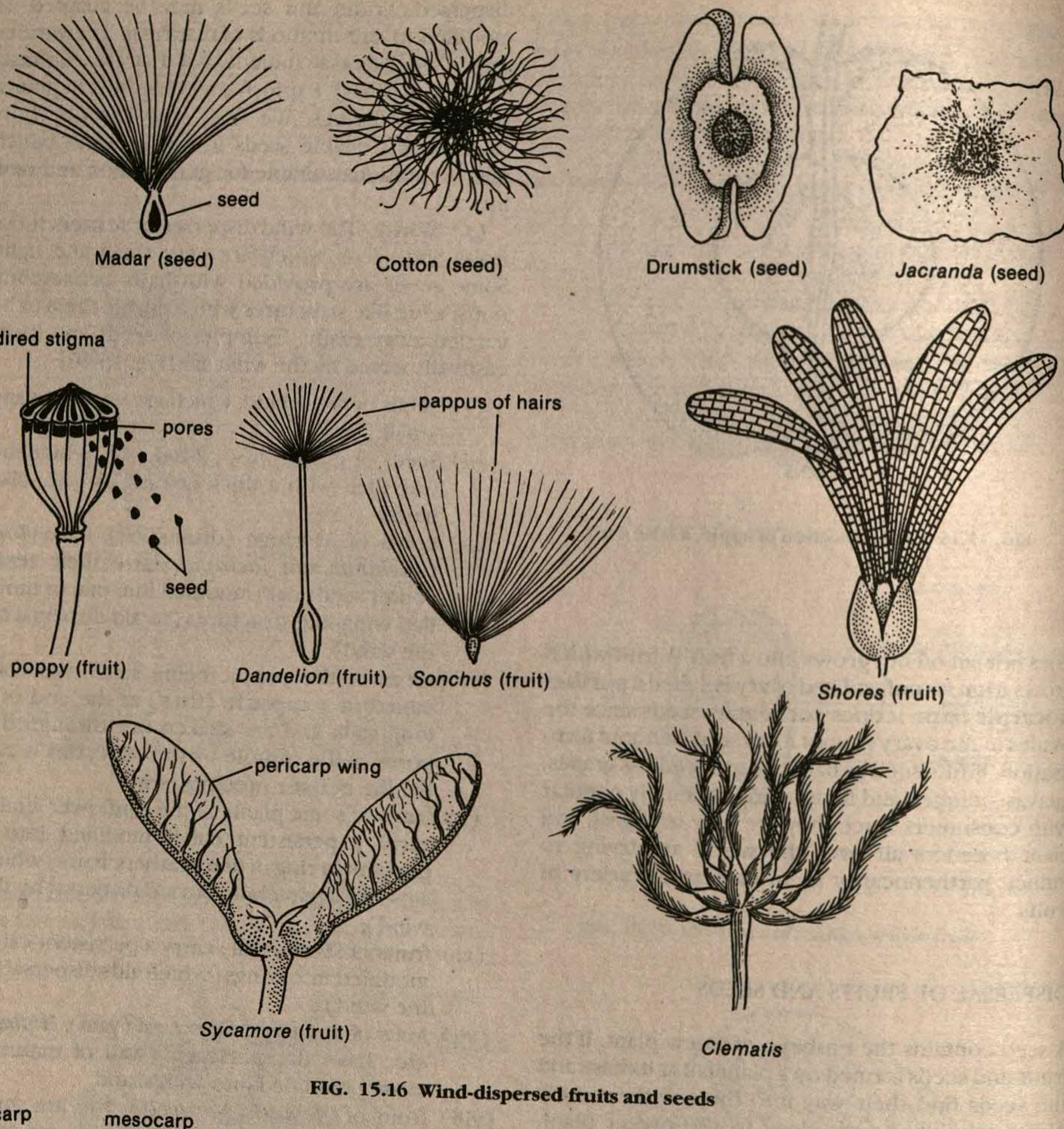


FIG. 15.16 Wind-dispersed fruits and seeds

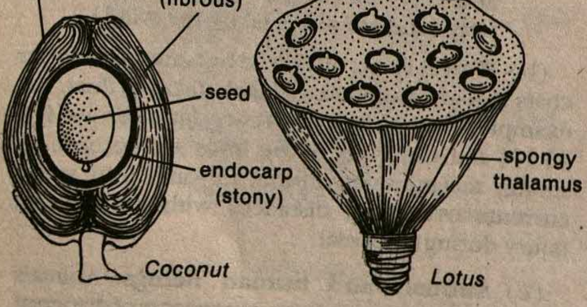
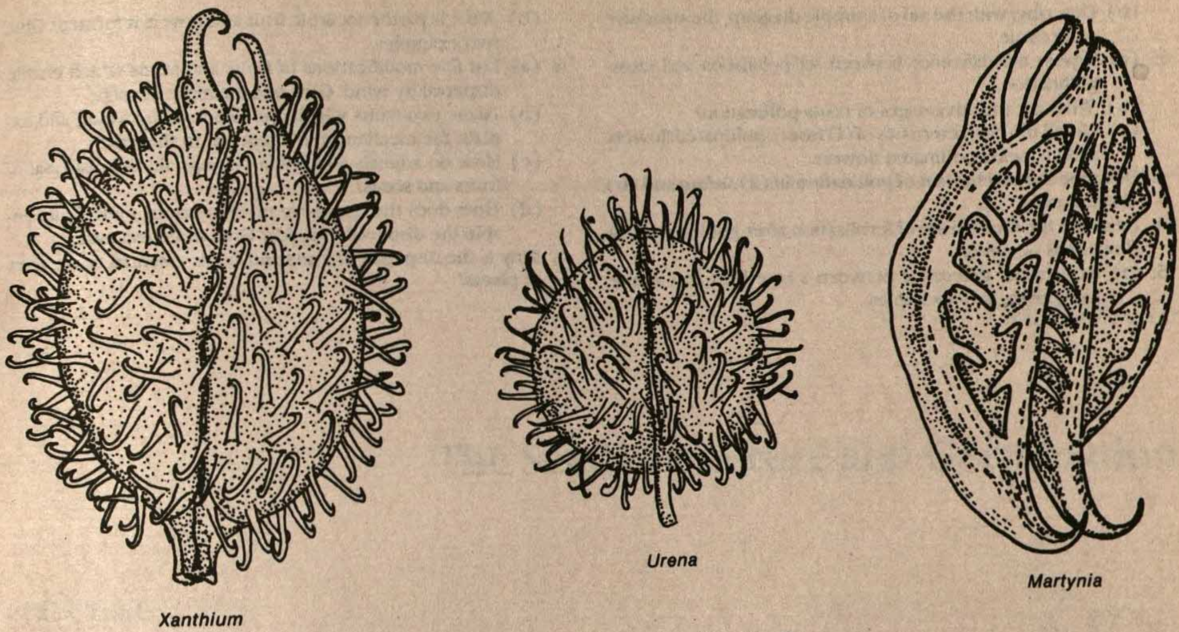


FIG. 15.17 Water-dispersed fruits

of fruits and seeds. Fruits and seeds are modified in two ways to suit dispersal by these agents:

First, some fruits are provided with hooks, spines, barbs, bristles, stiff hairs, etc., on their outer coats. With the aid of these outgrowths, these fruits attach themselves to the furry coats or skins of some animals and are carried from one place to another [Fig. 15.18]. For example, the fruit of *Xanthium* has sharp, pointed stiff hooks and is dispersed by animals with furry coats. Similarly, seeds of *Pupalia*, *Martynia*, *Xanthium*, etc., also have



Hooks help to attach to the animal body.

FIG. 15.18 Animal-dispersed fruits and seeds

stiff hooks and are dispersed by animals in a similar way.

Secondly, many fruits, being fleshy and edible, are eaten by animals and human beings as food. In case of fruits like the mango, orange, and apple, the flesh is eaten and the seeds are thrown away, whereas, in case of fruits like guava, tomato, and brinjal, the seeds are eaten along with the flesh by many birds and later passed out of the alimentary canal in the faeces. The latter kind of seeds are protected from digestive juices by a woody or slimy seed coat (as in guava, tomato, etc.). In this respect, birds, human beings, and many other species of mammal are useful in dispersing fruits and seeds. Finally, farming, forestry, and gardening also help proper dispersal.

(d) **Explosive mechanisms in plants:** Many fruits, when ripe, burst with a sudden spasm and cause the seeds they contain to be scattered away from the parent plant (Fig. 15.19). Examples of such a mechanism are fruits of balsam, castor, *Phlox* and *Lupin*.

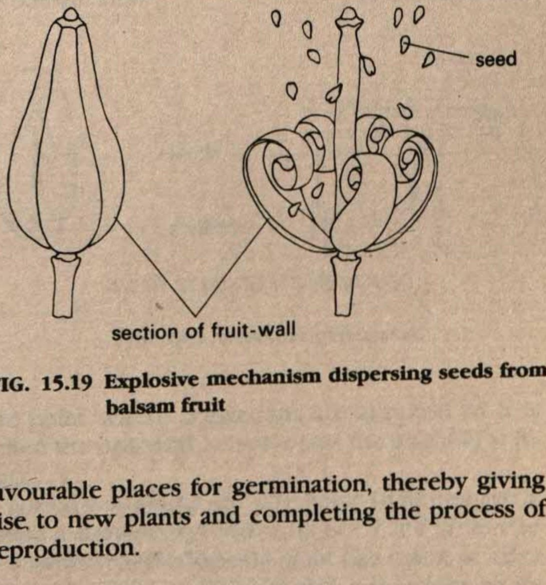


FIG. 15.19 Explosive mechanism dispersing seeds from balsam fruit

Thus, we may conclude that all the aforementioned means of dispersal enable seeds to reach favourable places for germination, thereby giving rise to new plants and completing the process of reproduction.

EXERCISES

1. (a) Discuss the structure and function of a pollen grain.

(b) Describe, with the aid of a simple diagram, the structure of an ovule.

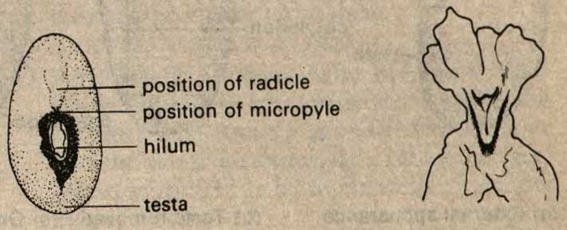
2. (a) Explain the difference between self-pollination and cross-pollination.
   (b) What are the advantages of cross-pollination?
   (c) List all the characteristics of (i) insect-pollinated flowers and (ii) wind-pollinated flowers.
3. Describe the mechanism of pollination in (a) *Salvia* and (b) Guinea grass.
4. Describe the mechanism of fertilisation after pollination of a flower has occurred.
5. (a) Explain the difference between a true fruit and a false fruit, giving two examples.
   (b) What is parthenocarpic fruit and how is it formed? Give two examples.
6. (a) List five modifications of fruits and seeds which enable dispersal by wind. Give one example of each.
   (b) Name two fruits which are dispersed by water, and explain the mechanism of dispersal in this case.
   (c) How do animals and human beings aid the dispersal of fruits and seeds?
   (d) How does the explosive mechanism of some fruits enable the dispersal of seeds? Give three examples.
7. Why is the dispersal of fruits and seeds essential to the lives of plants?

CHAPTER 16

The Seed: Structure and Germination

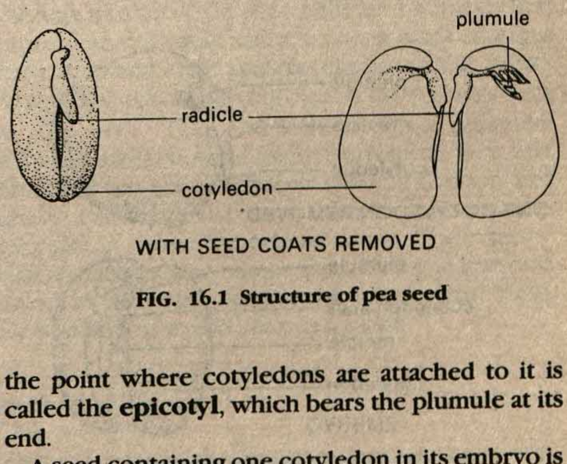
STRUCTURE

A seed develops from a fertilised ovule. The two integuments around the ovule become the **seed coats**, i.e., **testa** (outer seed coat) and **tegmen** (inner seed coat). The testa is much thicker than the tegmen, and is often very dry and hard. The seed coats effectively protect the embryo within. At the place where the seed breaks from the seed stalk (funicle of the ovule), there is a scar called the **hilum**, and above the hilum is a small pore called the **micropyle**. The micropyle is the pore through which the pollen tube enters into the ovule at the time of fertilisation. Sometimes, there is a ridge above the hilum, which is called the **raphe**. The entire fleshy and soft structure, as seen after removing the seed coats, is called the **embryo** or the baby plant. The embryo consists of one or two whitish fleshy bodies called the cotyledons and a short axis to which the cotyledons are attached. Cotyledons help store up the food material. The part of the axis which projects out of the cotyledons is called the **radicle**, while the part that lies between the two cotyledons is called the **plumule**. The plumule is surrounded at the apex by a number of minute delicate leaves. As the seed germinates, the radicle gives rise to the primary root and the plumule to the primary shoot.



EXTERNAL VIEW

RADICLE POCKET



WITH SEED COATS REMOVED

FIG. 16.1 Structure of pea seed

The part of the axis of the embryo lying below the point where cotyledons are attached to it is called the **hypocotyl**, which bears the radicle at its end. The part of the axis lying immediately above the point where cotyledons are attached to it is called the **epicotyl**, which bears the plumule at its end.

A seed containing one cotyledon in its embryo is called a **monocotyledonous seed** and gives rise to a **monocotyledonous** plant like maize or rice. Further, a seed containing two cotyledons in its embryo is called a **dicotyledonous seed** and gives rise to a **dicotyledonous** plant like pea, gram, bean or castor.

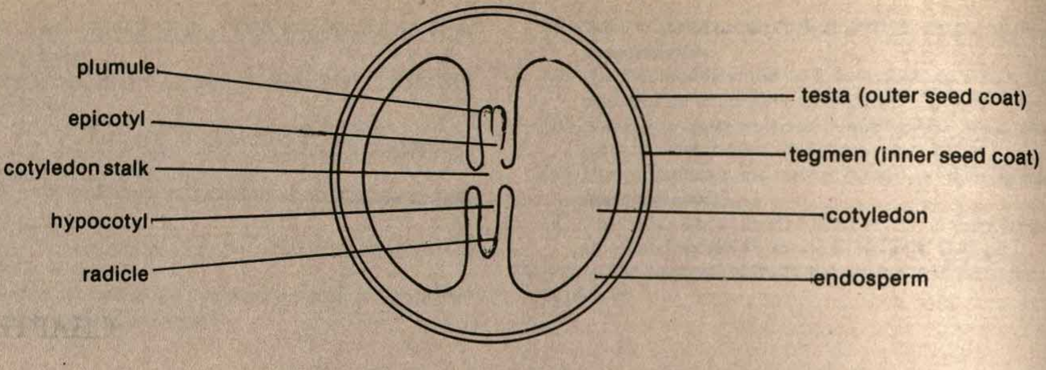
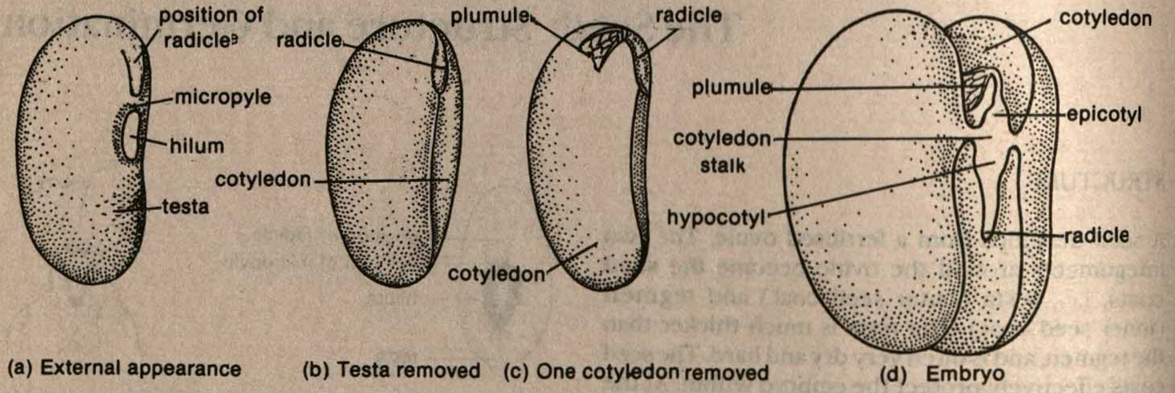


FIG. 16.2 Seed structure—generalised



(a) External appearance (b) Testa removed (c) One cotyledon removed (d) Embryo

FIG. 16.3 Structure of a bean seed

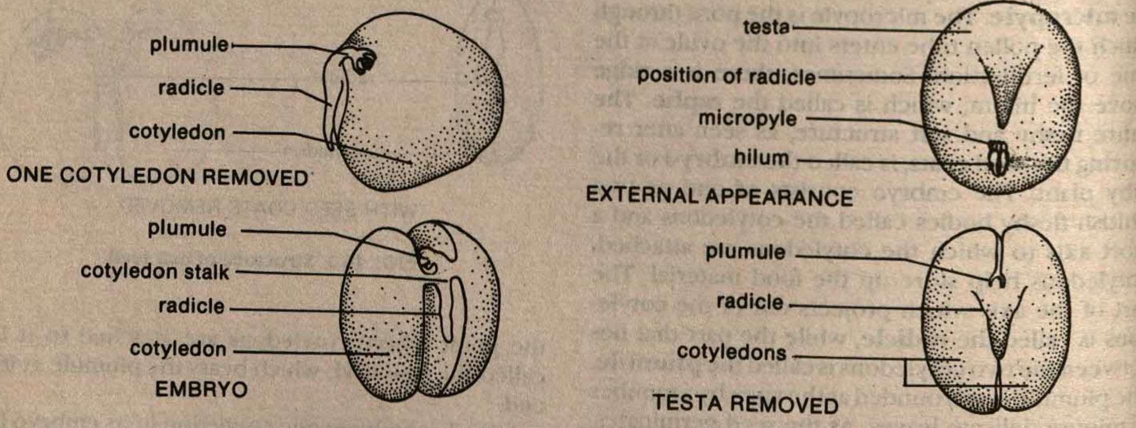


FIG. 16.4 Structure of a pea seed

Some quantity of food is stored in a seed to enable the embryo to survive till germination. A seed in which the cotyledons are large and swollen and can store food is known as an **ex-endospermic** or **ex-albuminous** seed. On the other hand, a seed in which the cotyledons are thin and flat has its food stored in the endosperm; such a seed is called an **endospermic** or **albuminous** seed. The endo-

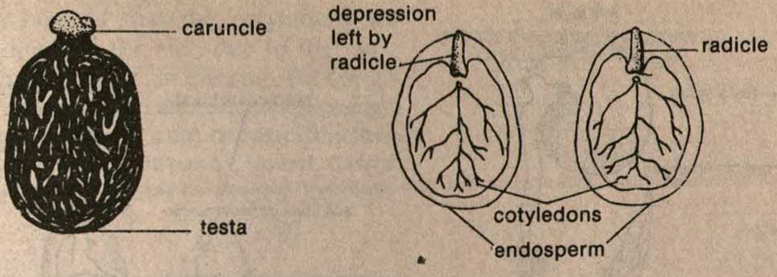
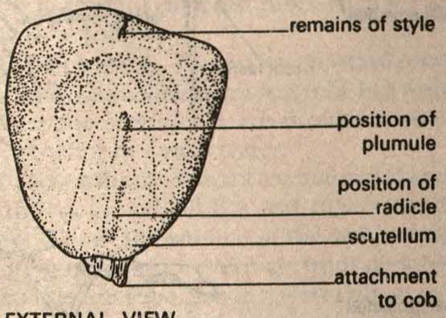
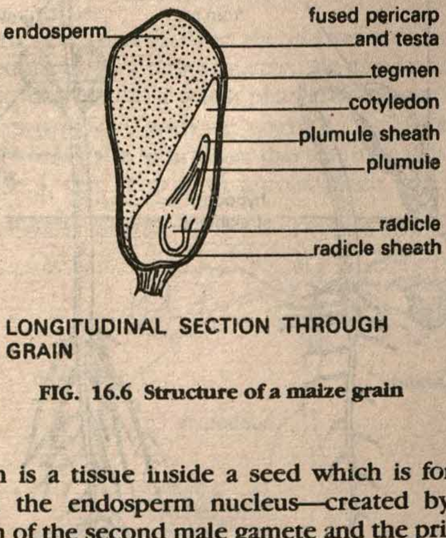


FIG. 16.5 Structure of a castor seed



EXTERNAL VIEW



LONGITUDINAL SECTION THROUGH GRAIN

FIG. 16.6 Structure of a maize grain

sperm is a tissue inside a seed which is formed when the endosperm nucleus—created by the fusion of the second male gamete and the primary endosperm nucleus in the ovule during fertilisation—divides repeatedly. Examples of exalbuminous seeds are beans, peas, and gram and those of albuminous seeds are castor, maize, and rice [Fig. 16.6].

GERMINATION

The embryo remains inactive or dormant in a dry seed, but when favourable conditions are available, it becomes active and develops into a small seedling. This process by which the inactive embryo becomes active and begins to grow is called **germination**. The conditions suitable for germination are:

(i) the presence of adequate moisture;
(ii) the presence of air or oxygen;
(iii) a suitable temperature; and
(iv) the presence of some light. In general, light has no direct influence on germination, but its presence facilitates the growth of the embryo into the seedling; that is, light influences germination indirectly by increasing soil temperature.

When the dry seed reaches an environment where water is available, it absorbs moisture, often through its micropyle and swells up. The seed coats rupture after a while and the young plant emerges from the seed. The **radicle** elongates and grows downward rapidly, giving rise to the primary root in the soil. The **cotyledons** soon separate, either partially or completely, from each other. The **plumule** appears between the cotyledons and grows upward (much more slowly than the radicle), giving rise to the primary shoot. The primary root and the primary shoot grow by using the food stored in the cotyledons or the endosperm. Thus, the seedling of a new plant is formed.

TYPES OF GERMINATION

During germination, the shoot emerges from between the cotyledons. The cotyledons may remain underground while the seedling develops, or they may emerge above the ground. Depending on the behaviour of the cotyledons, we may classify germination into two types:

(a) **Hypogeal germination**: During this kind of germination, the cotyledons remain under-

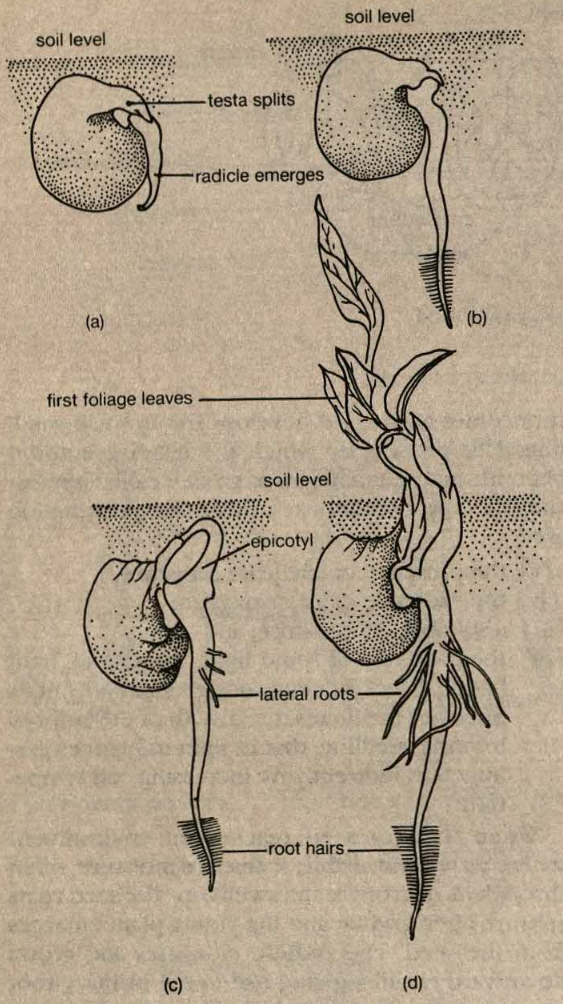


FIG. 16.7 Hypogeal germination in pea

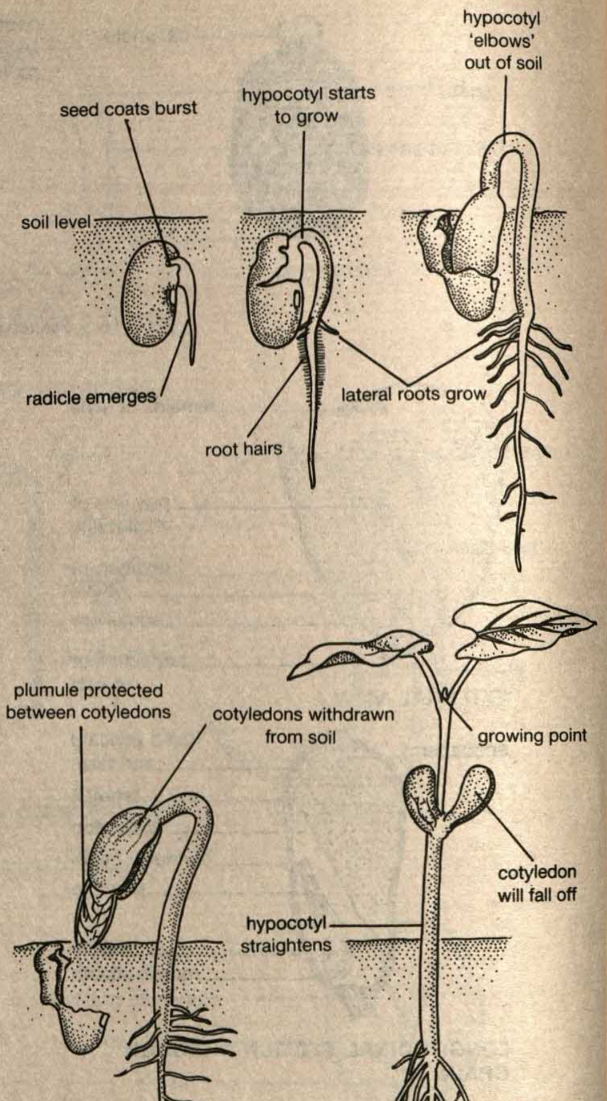


FIG. 16.8 Epigeal germination in bean

ground or lie just on the surface of the soil. The epicotyl elongates and pushes the plumule upwards. In this case, the cotyledons do not become green; in fact, they gradually dry up and fall off.

Seeds of pea, gram, mango, groundnut, radish, mustard, maize, etc., undergo hypogeal germination (Fig. 16.7). In the pea seed, after the seed has absorbed moisture, the radicle comes out through the micropyle and grows downwards to form the primary root. The seed coats burst and the epicotyl elongates to take the form of a loop. The plumule emerges out of the cotyledons, between which it has remained hidden till this stage. The epicotyl elongates further, straightens up and finally the leaves emerge from the plumule and turn green in colour. During germination, the food stored in the cotyledons is utilised.

(b) **Epigeal germination**: During epigeal germination, it is noticed that the cotyledons are pushed upward, above the soil, due to the rapid elongation of the hypocotyl. In this case, the cotyledons usually become green and manufacture food for the growing seedling for a day or two. They then dry up and fall off. Seeds of beans, gourd, castor, cotton, tamarind, etc., undergo epigeal germination.

Activity 1: To find the conditions necessary for germination.

Take four test tubes. Place some **dry** cotton wool at the bottom of each test tube. Then set up the apparatus as follows:

In test tube 1: Place a few mustard seeds on the cotton wool and keep this test tube in a warm place, so that the seeds in it are provided with air and warmth, but not with water.

In test tube 2: Place a few mustard seeds on the cotton wool and fill the test tube with **distilled** water. Cover the surface of the water with a layer of oil in order to prevent air from dissolving in it. Keep this test tube also in a warm place, so that the seeds in it are provided with warmth and water, but not with air.

In test tube 3: Wet the cotton wool with **tap** water and place a few mustard seeds on it. Keep this test tube also in a warm place, so that the seeds in it are provided with air, warmth, and water.

In test tube 4: Arrange this test tube just like test tube 3, but keep it in a cold place (e.g., a refrigerator) so that the seeds in it are provided with air and water, but not with warmth.

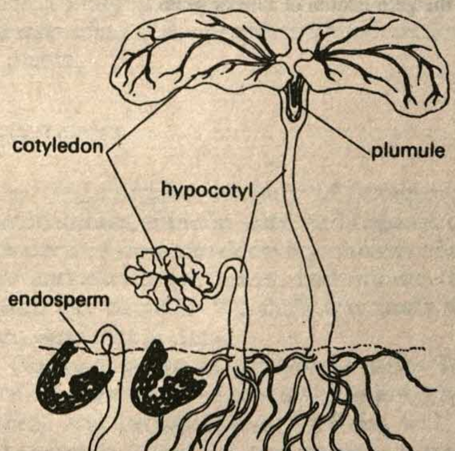


FIG. 16.9 Epigeal germination in a castor seed

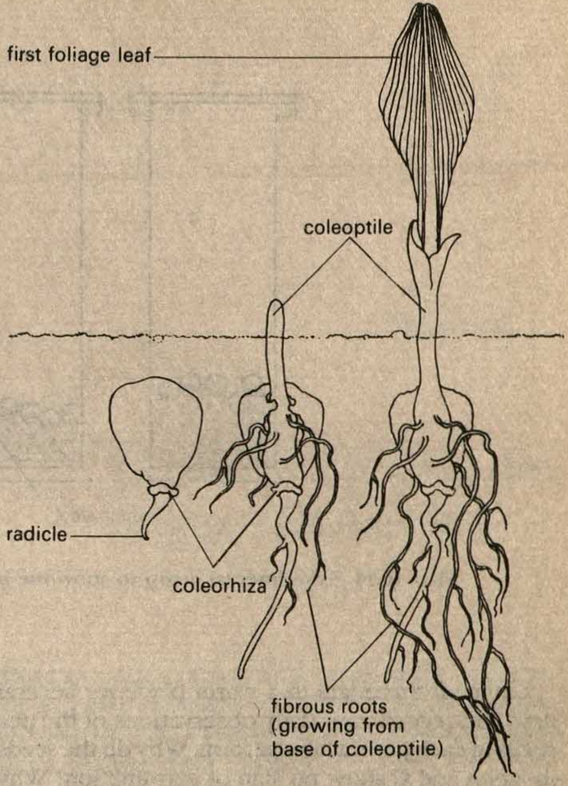


FIG. 16.10 Germination of maize grain

Observe these four test tubes for four or five days, and carefully record your daily observations in a tabular form. In which test tubes do the seeds germinate? What does this tell you about conditions necessary for germination?

Activity 2: To show the importance of oxygen and water for germination.

Set up three jars as shown in Fig. 16.11. **Jar A** contains dry cotton wool and dry pea seeds; **jar B** contains wet cotton wool and soaked pea seeds; and **jar C** contains a solution of alkaline pyrogallol (1 g of pyrogallic acid dissolved in 10 cm^3 of a 10% solution of sodium hydroxide). Into this solution is dipped the open end of an inverted U-tube The other end of the U-tube is corked and contains soaked pea seeds and wet cotton wool. The alkaline pyrogallol absorbs the oxygen in the U-tube, so that the pea seeds are provided with moisture but no oxygen.

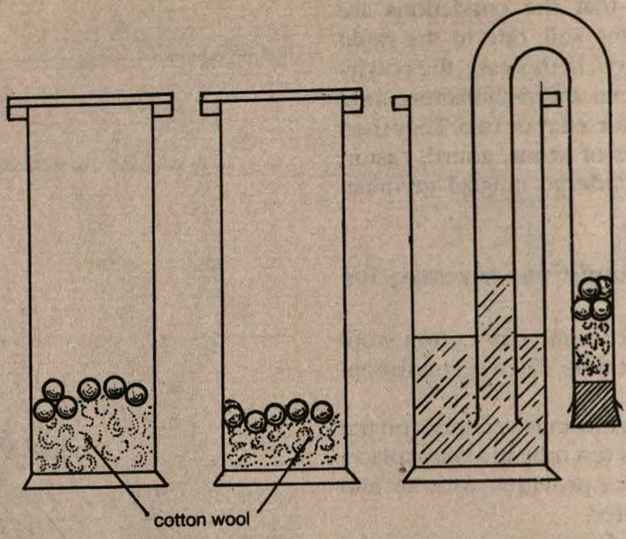


FIG. 16.11 Experimental setup to show the importance of oxygen and water for germination

Leave all three jars in a warm place for several days and record your daily observations of the pea seeds in each jar in a tabular form. Why do the seeds in jars A and C show no sign of germination? Why do those in jar B germinate?

EXERCISES

1. Distinguish, with the aid of examples, between endospermic and non-endospermic seeds.
2. List all the parts of one endospermic seed and one non-endospermic seed and state the function of each part.
3. What are the essential conditions for the germination of seeds?
4. What are the differences between epigeal germination and hypogeal germination?
5. Draw a series of labelled diagrams to show the various stages in the germination of a maize grain.

CHAPTER 17

The Soil: Constituents, Types, and Fertility

Green plants that grow on land depend on the soil for mechanical support, and for water and mineral salts, which provide the raw material necessary for their growth. Their roots respire by using the air present between the particles of the soil. Besides, the functions of these plants depend considerably on the various living organisms (e.g., bacteria, earthworms) which inhabit the soil, since these organisms change its physical and chemical make-up. Thus, a study of the nature of soil is essential to an understanding of the properties and functions of green plants.

CONSTITUENTS

Soil is a very complex mixture of numerous inorganic materials, mineral salts, and organic compounds derived from the decaying remains of dead animals and plants, air, water, and minute living organisms like bacteria. We shall now studv some of its constituents in detail.

(a) INORGANIC MATERIALS AND MINERAL SALTS: These are formed from rocks which are constantly being weathered and broken down. Particles with diameters between 2 and 0.2 mm constitute **coarse sand**; those with diameters between 0.2 mm and 0.02 mm constitute **fine sand**; those with diameters between 0.02 and 0.002 mm constitute **silt**; and those with diameters less than 0.002 mm constitute **clay**. Chemically, sand is made up of **silicon dioxide** usually mixed with **ferric oxide**, whereas silt and clay are mixtures of **silicates**, **sulphates**, and **phosphates** of such metals as **sodium**, **potassium**, **magnesium**, **aluminium**, **iron**, and so on. These mineral salts form a very dilute solution with the water present in the soil, and are vital to the growth of plants.

(b) HUMUS: This is dark brown non-living organic matter which is rich in nitrates and other mineral salts essential for plant growth, and prevents soil erosion. It consists of the dead remains of living organisms (specially plants) and also their waste products which are being decomposed by microorganisms in the soil. It is present predominantly at, or near, the soil surface since dead organic materials of most plants and animals, and their wastes, fall and accumulate here initially after their death.

(c) AIR: Except in water-logged soil, air is always present in the spaces between particles of soil. Since particles of sand are loosely packed together, there is more air in a given volume of sand than in the same volume of clay. This air is used for respiration by plant roots and organisms living in the soil.

(d) WATER: This is very important constituent of soil, and is present as capillary water around the soil particles (as a thin film which is formed due to surface tension). Water is also held strongly within the soil particles (hygroscopic water), but this water cannot be absorbed by roots. The soil water contains dissolved air and mineral salts such as those mentioned in (a) above. Plant roots absorb the dilute solution and thus obtain both water and mineral salts.

(e) SOIL ORGANISMS: A variety of small and large organisms live in the soil, controlling its texture and fertility. **Bacteria** are present in large numbers, up to a few million per gram of soil, and along with soil **fungi**, they bring about the decay of dead organisms. This enriches the soil in the humus. **Nitrogen-fixing bacteria** help to change nitrogen, present in the air in the soil, into various nitrogenous compounds which dissolve in soil water and are then absorbed by plant roots. **Earthworms** make the soil porous by burrowing through, and also enrich it in nitrogenous compounds contained in their wastes (faeces). Rats, moles, ants, rabbits, snakes, etc., also burrow into the soil and help to make it more porous, thus improving its fertility, aeration, and drainage.

TYPES OF SOILS

Different types of soils are found all over the world, and even within India. These different types arise as a result of the different proportions in which their constituents are combined. We shall now describe the three main types of soils.

(a) CLAY SOIL: This type of soil is often called **heavy soil**. In this soil, which is a mixture of clay and silt, the particles are packed closely leaving little room for air. It contains over 50% of clay particles, which are highly impervious to water. Thus, it prevents easy drainage of water and may easily become water-logged. One advantage of this soil is that it can retain its water content through drought as well, since it does not dry up quickly. When dry, it forms hard clods or lumps. Since drainage is poor in clay soil, it retains dissolved mineral salts and provides a rich source of these salts.

(b) SANDY SOIL: This type of soil is often called **light soil**. It consists mainly of sand particles (more or less 60%), which are loosely packed and have large spaces between them. This soil also contains a small proportion of clay and silt, about 10% of each. This soil is well aerated and water is drained out of it easily and quickly. Since it holds little water, it gets warmer in the sun than clay soil does. Because of the high drainage, this soil has a low content of mineral salts, and artificial fertilisers must be added to it to achieve successful cultivation. Its humus content also is very low.

TABLE 17.1 COMPARISON OF CLAY AND SANDY SOILS

	CLAY SOIL	SANDY SOIL
1.	Contains over 50% clay particles with diameters less than 0.002 mm.	Contains nearly 60% sand particles with diameters more than 0.02 mm.
2.	Particles are closely packed (**less porous**).	Particles are well separated (**more porous**).
3.	Subsoil water can rise to a high level (**good capillarity**).	Subsoil water cannot rise to a high level (**poor capillarity**).
4.	Has small air spaces.	Has large air spaces.
5.	Water-holding capacity is good.	Water-holding capacity is poor.
6.	Rich in mineral salts and humus (**fertile**).	Poor in mineral salts and humus (**infertile**).
7.	Usually wet and cold.	Usually dry and warm.
8.	Heavy and difficult to work.	Light and easy to work.

(c) LOAM: This is a mixture of both clay and sand. It contains 30–35% of silt and 5–25% of clay while the rest is fine sand. The clay provides it with a high content of mineral salts and humus and a good ability to hold water. The sand makes it light and easy to work with; it also provides aeration and prevents water-logging. Thus, loam is better suited for agriculture than either pure clay or pure sandy soil.

Activity 1: To determine the percentage by volume of air in a sample of soil.

Take a small tin (jam tin) open at one end and press the open end down into a soft patch of ground until the tin gets filled with soil. Care should be taken to ensure that the degree of compression (or looseness) of the soil in the tin is the same as that of the soil in the ground. Level off the sample at the top of the tin. Next, take 200 cm^3 of water in measuring cylinder with a capacity of 500 cm^3. Transfer all the soil from the tin to the cylinder, stirring the water until all the air between the soil particles has escaped. Record the total volume of water plus soil. Find the internal volume of the tin by filling it to the brim with water and pouring this water into another measuring cylinder. On the basis of these observations, calculate the percentage by volume of air in the sample of soil as follows:

Volume of soil plus contained air = internal volume of tin = x cm^3

Volume of water in measuring cylinder = 200 cm^3

Volume of water plus soil minus air in measuring cylinder $=(200+y)\text{cm}^3$
∴ Volume of soil without air $=y'\text{cm}^3$
And volume of air in sample of soil $=(x-y)\text{cm}^3$
∴ Percentage by volume of air in soil $=\dfrac{100(x-y)}{x}$

Activity 2: To determine the percentage by weight of water in a sample of soil.
Weigh a small basin. Put some soil into the basin and weigh it again. Now, place the basin in a steam oven to dry the soil. Weigh the basin from time to time; if the basin weighs the same, twice or thrice consecutively, this indicates that all the soil water has been dried off. The final constant weight is that of the basin with dry soil. From these observations, the percentage by weight of the water contained in the soil may be calculated as follows:

Weight of empty basin $=A$ g
Weight of basin plus soil with water $=(A+x)$g
∴ Weight of soil with water $=x$ g
Weight of basin plus dry soil $=A+y$g
∴ Weight of dry soil $=y$ g
∴ Weight of water contained in sample of soil $=(x-y)$g
∴ Percentage by weight of water in soil $=\dfrac{100(x-y)}{x}$

You may perform this experiment using soils taken from different parts of the city or town you live in, and also with the soil from the same place during different times of the year. Study and explain the variations you obtain in your results.

Note: It may so happen that while drying the soil in the oven, some of the humus in the sample decomposes. In such a case, the loss of weight observed will be more than the actual value due to drying off of the water.

Activity 3: To determine the percentage by weight of the humus in a sample of soil.
For this experiment, use the dry soil obtained from Activity 2. Heat the soil strongly until it is red hot, stirring it gently with a metal rod. Continue heating until the soil stops giving off smoke and attains a constant weight.

During this heating, all the humus in the sample is decomposed, and the final constant weight is that of the soil without any organic content. The percentage by weight of humus in the sample may be calculated as follows:

Original weight of soil with water $=x$ g
Original weight of basin plus dry soil $=(A+y)$ g
Final weight of basin plus dry soil without humus $=(A+z)$ g
∴ Weight of humus $=(A+y)$ g$-(A+z)$g
$=(y-z)$ g
∴ Percentage by weight of humus in soil sample $=\dfrac{100(y-z)}{x}$

Activity 4: To compare the water-retaining properties of clay and sandy soils.
Set up the apparatus as shown in the diagram (Fig. 17.1). Place some dry sandy soil in the funnel after plugging it with a little cotton wool. Place the funnel over a measuring cylinder. Set up a similar apparatus in the same way, but use an equal quantity of dry clay soil in it instead of sandy soil. Tap both the funnels gently to ensure that the respective soils in them have settled. Pour an equal volume of water (say, 50 cm³) into each funnel. Using a stopclock or stopwatch, measure the time required by the water in each funnel to drain out How much faster does the water drain out of the sandy soil than out of the clay soil? How does the porosity of the sandy soil compare with that of the clay soil? Measure the volume of water in each measuring cylinder when drainage from the funnels has ceased and calculate the volume of water retained in the soil. Which soil retains more water? Explain why. What bearing does this factor have on the fertility of a soil?

Activity 5: To compare the capillarity in clay and sandy soils.
Set up the apparatus as shown in the figure [Fig. 17.2]. The two long, wide glass tubes are plugged with cotton wool and filled with dry sandy soil and dry clay soil, respectively. Tap the tubes several times to ensure that the soils have settled in them. Then immerse their lower ends in water, as shown, and leave the apparatus in that position for several

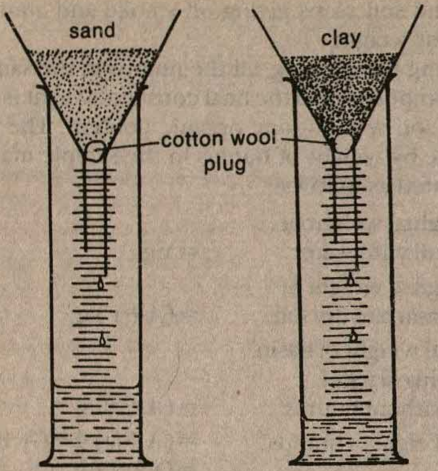


FIG. 17.1 Experimental setup to compare water-retaining properties of sandy and clay soils

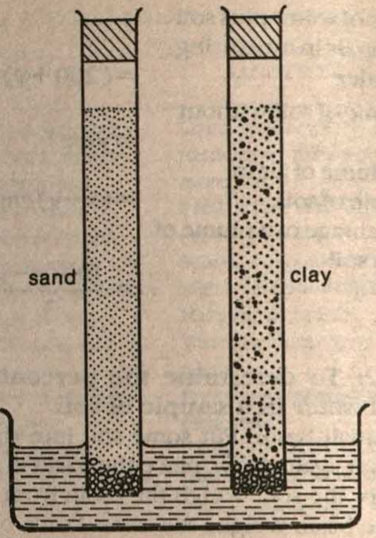


FIG. 17.2 Experimental setup to compare the capillarity in clay and sandy soils

days. You will observe that water rises in the sandy soil, very rapidly in the first few hours and more slowly over the next one or two days. When does water stop rising in the sandy soil? In the clay soil, water rises slowly but steadily for several days. When does water stop rising in the clay soil? What are the levels of water in the two tubes after several days? From this, what do you infer about the **capillarity** of sandy and clay soils?

FERTILITY AND IMPROVEMENT OF SOIL

The quality of the soil in a particular place or region is the chief concern of the agriculturist. For him, the soil must suit the requirements of the various crops he cultivates. Both the physical make-up as well as the chemical constituents of the soil are important in this regard. Besides, the agriculturist is also concerned with the organisms living in the soil, since some of them make it more fertile while others destroy the crops. We shall now discuss some of these aspects.

(a) PHYSICAL IMPROVEMENT: If the soil is sandy, then water drains away too quickly and the content of mineral salts is poor. To counter this, the farmer often mixes clay soil or even humus with the sandy soil in his fields to improve its quality. This addition increases both the water-holding capacity and the mineral salt content of the soil.

It is mainly clay soil in the fields which the farmer finds difficult to till, and, often, finds them waterlogged. To overcome this problem, he adds sandy soil until the right drainage capacity and texture of soil are obtained. Similarly, if lime is added to clay soil, it enables the minute particles of clay to **flocculate** (become bunched together). This makes the clay behave as though it were made up of larger particles, and increases its porosity and aeration and decreases its tendency to get waterlogged. In this context, it should be noted that the addition of the manure of compost to the sandy soil not only increases its fertility but also improves its water-holding capacity.

(b) FERTILISERS: A soil is said to be **fertile** if it can support an abundant growth of plants. A soil supports plants by providing them directly with water and mineral salts. If a soil does not possess a sufficient content of either water or mineral salts, it is said to be **infertile**. When a seasonal crop is grown in a field, it takes away most of the mineral salts contained in the soil. This loss has to be made good. Although Nature has devised many ways to replenish exhausted soil, the land cultivated by human beings has to be supplied with additional man-made chemicals to maintain fertility. A **fertiliser** is a chemical which enriches the soil in one or more mineral salts. Both **natural fertilisers** such as manure (made from the excreta of farm animals) and compost (decayed plant and animal matter) and **artificial fertilisers** such as urea, calcium superphosphate, ammonium nitrate, calcium ammonium nitrate, and ammonium sulphate, should be added to make cultivated soil fertile.

Natural fertilisers are forms of humus, and, consequently, change the chemical as well as the physical properties of soil. For example, when manure or compost is added to sandy soil, the natural fertiliser increases the water-holding capacity of the soil. Similarly, if lime is added to clay soil, the benefit obtained is the same as mentioned earlier under (a).

(c) ROTATION OF CROPS: Different types of plants consume different mineral salts from the soil. For instance, most cereals absorb nitrogenous compounds. After each season the soil needs to be replenished with nitrogenous compounds. One of the best natural ways to replenish the soil with nitrogen compounds and increase its fertility is by the process of **rotation of crops**. An example will serve to illustrate this process. Leguminous (pod-bearing) plants like pulses, beans, groundnut, *Crotolaria* (hemp), *Sesbania*, and lucerne, have **nodules** which house bacteria. These bacteria convert the nitrogen in the soil air into nitrogenous compounds. Some quantity of these compounds is absorbed by the plants; the rest is partly stored in the nodules and partly returned to the soil. This again increases the nitrogen content of the soil. Therefore, after one season of leguminous plants, the farmer can again grow an abundant and healthy cereal crop. Since the nodules store some nitrogenous compounds and the plant also is rich in such compounds (proteins), their remains are often ploughed into the soil after harvest in order to improve the fertility of soil (green manuring).

To cite a specific case: Leguminous plants like *Tephrosia* and *Derris* are grown in tea gardens to replenish the nitrogenous content of the soil there.

(d) THE NITROGEN CYCLE: Although nitrogen occurs to the extent of about 78% in the air, it cannot be used by the plants in its free state. Being an essential constituent of proteins, chlorophyll, and protoplasm, it is indispensable for the survival of living organisms.

Green plants absorb nitrates from the soil and make use of the nitrogen present in them for the synthesis of proteins. Since atmospheric nitrogen is the ultimate source for the formation of nitrates in the soil, there could be a possibility of the atmosphere becoming poorer in nitrogen. However, in Nature, this is not allowed to happen since there is a continuous circulation of nitrogen in the living world first among plants, animals, and decomposers and secondly between the living and non-living worlds. This circulation is called the **nitrogen cycle** in which Nature provides a system for the constant renewal of nitrogen.

The nitrogen cycle consists of activities and processes by which soluble nitrates formed in the soil due to natural phenomena like lightning and by the activities of some microorganisms are removed from the soil by the green plants. This cycle also consists of the processes by which nitrates are returned to the soil by the activities of other microorganisms. Figure 17.3 relates to the circulation of nitrogen with reference to land organisms. An equivalent cycle occurs in water too.

Soluble nitrates formed in the soil are absorbed by the plants and converted into proteins in their body. When animals feed on plants, they take up the plant proteins. When animals excrete and plants shed their old leaves, and also when animals and plants ultimately die, their wastes and dead remains are absorbed in the soil and decomposed or decayed by microorganisms. i.e., **saprophytic bacteria** and fungi. Next, the proteins contained in their bodies are again converted into nitrates in several stages and again absorbed by plants. At the same time, a portion of the nitrates present in the soil is disintegrated by denitrifying bacteria into free nitrogen which then escapes into the air.

Microorganisms, specially bacteria, play an important role in the nitrogen cycle. Some of the important bacteria present in the soil and involved in the nitrogen cycle are as follows:

(i) Saprophytic or putrefying bacteria live on and feed on the dead organisms and their wastes and gradually reduce the proteins and the nitrogenous compounds contained in them to amino acids and then to ammonia. (These bacteria are also called **ammonifying bacteria** and the process is called **ammonification.**) These bacteria are active in the absence of oxygen.

(ii) Nitrifying bacteria are those bacteria which nitrify ammonia compounds formed in the soil into nitrates by oxidation. This process is called **nitrification**, which takes place in two stages in the presence of oxygen. In the first stage, ammonium compounds are acted on by nitrite bacteria (*Nitrosomonas*) and oxidised into nitrite and, in the second stage, the nitrite thus formed is then acted on by nitrate bacteria (*Nitrobacter*) and further oxidised to nitrate. The nitrates thus formed are readily absorbed by green plants.

(iii) Nitrogen-fixing bacteria fix the gaseous nitrogen of the air, i.e., combine it with other elements and ultimately make it available to the

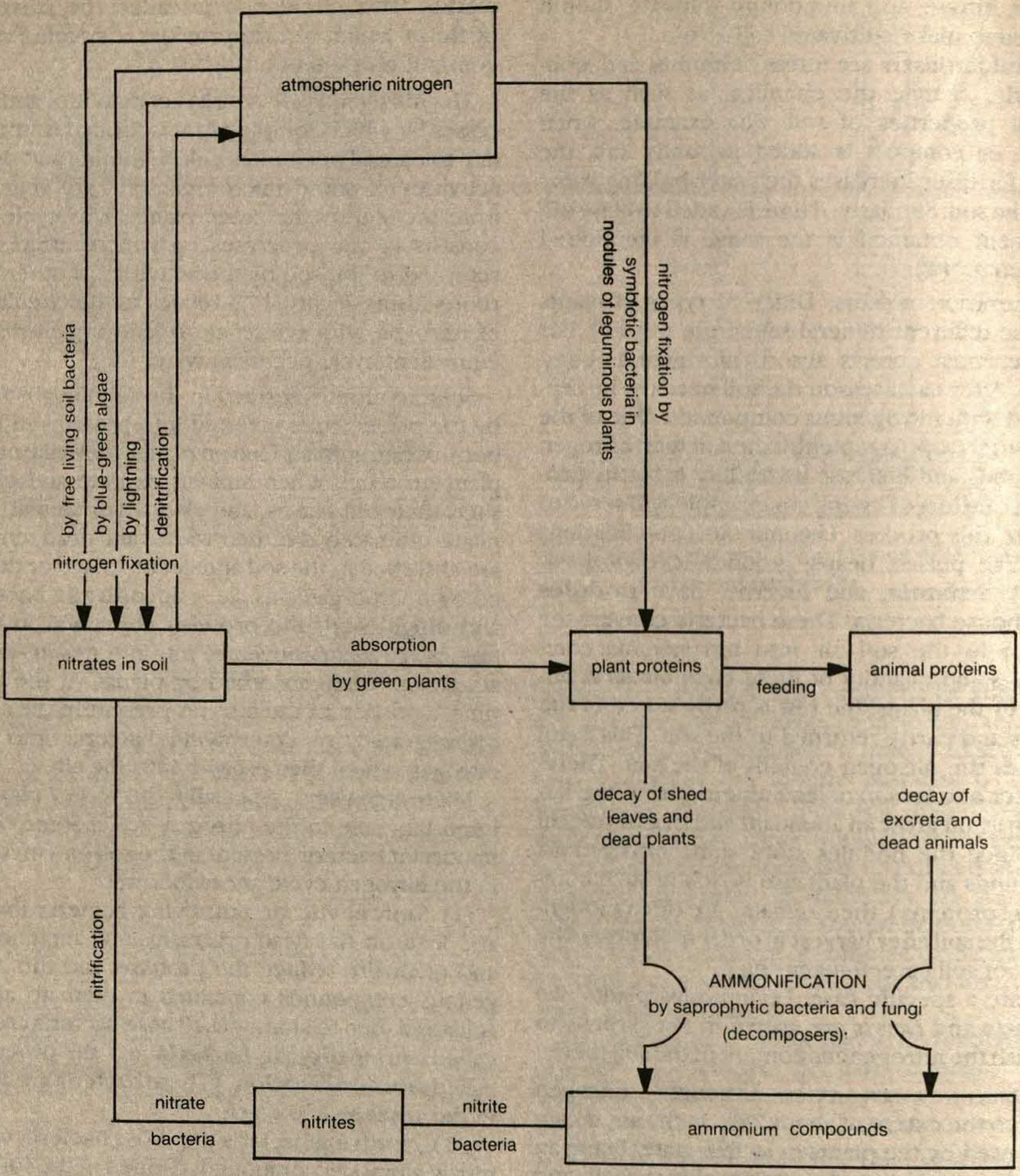


FIG. 17.3 The nitrogen cycle in land organisms

plants as compounds of nitrogen in the soil. Let us consider this aspect in some detail.

First of all, certain types of free living soil bacteria (*Azotobacter* and *Clostridium*) fix free nitrogen of the soil air in their own bodies in the form of amino acids and finally build up proteins from them. After the death of these bacteria, the proteins are released into the soil. Further, by ammonification and nitrification, these proteins are transformed into nitrates which are then used by green plants.

Secondly, symbiotic bacteria (*Bacillus radicicola*) live in the nodules of leguminous plants. These bacteria have the power of fixing the free nitrogen of the soil air in the form of nitrogenous compounds. Some portion of these compounds is absorbed into the leguminous plant, another portion is released from the nodules into the soil, and the remaining portion stays locked up within the nodules. Thus, the soil becomes rich in nitrogenous compounds, particularly if the nodule-bearing leguminous plants are ploughed into the soil. In this association, called **symbiosis**, both the leguminous plant and the bacteria benefit from each other; the former supplies the bacteria with carbohydrates and the latter supply the leguminous plant with nitrogenous food.

Besides bacteria, there are certain blue-green algae such as *Nostoc* and *Anabaena* that are commonly found in soil and water and which fix free nitrogen. The nitrogenous compounds formed by their activity are released into the soil or water after their death. These compounds are converted by ammonification and nitrification to nitrates for the use of green plants.

(e) NITROGEN FIXATION BY ELECTRIC DISCHARGE: To some extent, free nitrogen and oxygen present in the atmosphere combine during a flash of lightning in a storm to form **nitric oxide.** Nitric oxide dissolves in rain water to form a very weak solution of nitrous and nitric acids. This solution enters the soil on reaching the ground and forms nitrites and nitrates of metallic elements present there. These compounds are soluble in soil water and are absorbed by green plants.

EXERCISES

1. What should be the constituents of a good garden soil? State the importance of each constituent.
2. Bring out the differences, in a tabular form, between a clay soil and a sandy soil.
3. (a) Why are fertilisers important for the growth of crops?
   (b) What type of fertiliser is the best for plant growth and why?
4. Explain the following terms: (i) green manuring; (ii) rotation of crops; (iii) nitrogen fixation; (iv) reciprocal symbiosis; (v) ammonification; and (vi) flocculation.
5. Briefly outline the nitrogen cycle in Nature and state its importance.

CHAPTER 18

The Physiology and Functions of a Flowering Plant

As you would have realised by now, the structure and functions of a flowering plant are highly complex. Different parts of the plant perform different—and usually specialised—functions. We shall now study these aspects in some detail.

SECTION 1: THE ABSORPTION OF WATER AND MINERAL SALTS

The root system of a flowering plant absorbs, from the soil, water and mineral salts, which are essential for survival and growth. Both monocotyledonous and dicotyledonous plants possess **root hairs** which are long, fine, unicellular extensions from the outermost cells of branch roots. To understand how the cell membrane and the cell wall of a root hair enable it to absorb water and dissolved substances from the soil, we must first understand the meaning of the terms **diffusion**, **active transport**, and **osmosis.**

DIFFUSION

Diffusion is the process by which the molecules of a substance (solute, solvent, or gas) move from a region of their high concentration to one of low concentration. This movement continues until, eventually, the molecules are uniformly distributed throughout the entire volume available to them. Diffusion also proceeds whenever or wherever there exists a diffusion gradient. Any number of substances can diffuse independently of each other and the rate of diffusion depends upon the size of the molecules and the temperature. For example, if a crystal of potassium permanganate is added to a glass of water, it dissolves and gradually the purple colour spreads until, eventually, it is uniformly distributed.

ACTIVE TRANSPORT

Active transport is, in a sense, the inverse process of diffusion. In diffusion, the molecules of a substance are transferred from a region of their higher concentration to that of lower concentration, whereas in active transport the molecules are transferred from a region of lower concentration to one of higher concentration. Such a movement can be accomplished only by using up the energy liberated during cell respiration. Most living cells can carry out active transport.

OSMOSIS

Osmosis is a particular type of diffusion which occurs across a semi-permeable membrane. A **membrane** is a thin, soft, pliable sheet, usually of plant or animal origin. If it has pores large enough to allow molecules of a fluid to pass through them, it is called a **permeable membrane**. For instance, raisins have a permeable membrane. If dry raisins are soaked in tap water for several hours, they swell up because water molecules enter them through the pores of the membrane, and the water around them becomes sweet because molecules of sugar diffuse out through the membrane.

If a membrane has pores large enough to allow molecules of the solvent (water, in the case of raisins) to pass, but too small to let molecules of the solute (sugar) to pass easily through them, it is called a **semi-permeable**, or **differentially** or **selectively permeable membrane**. If such a membrane separates two solutions of unequal concentration, the solvent (say, water) from the solution of lower concentration diffuses through this membrane into the solution of higher concentration until the concentrations of both solutions become equal. This diffusion of a solvent (which is commonly water), from a less concentrated solution (with a higher concentration of solvent molecules per unit volume) to a more concentrated solution (with a lower concentration of solvent molecules per unit volume) through a semi-permeable membrane, is called **osmosis**. Thus, osmosis consists of the diffusion of solvent molecules across a semi-permeable or differentially or selectively permeable membrane.

Activity 1: To demonstrate osmosis.
Take a piece of semi-permeable membrane (e.g., egg membrane, cellophane paper or sheep's or goat's or pig's bladder) and tie it tightly over the mouth of a thistle funnel with cotton thread [Fig. 18.1]. Make the joint water-tight by sealing it with melted wax. Then invert the funnel and pour a highly concentrated sugar solution through the stem into the bowl of the funnel. Mark the level A of the solution on the outside of the stem of the funnel, and immerse the bowl covered with the membrane into a beaker filled with distilled water. Clamp the funnel in this position and leave the apparatus aside for a few hours. Does the level in the thistle funnel rise or fall during this interval of time? Mark the new level B. Test the distilled water in the beaker for the presence of sugar in it. What do this test and the change in level tell you about osmosis? How rapidly does osmosis occur? Try comparing the rates of osmosis using different semi-permeable membranes with the same original concentration of sugar solution, and also using different concentrations of sugar solution with the same membrane.

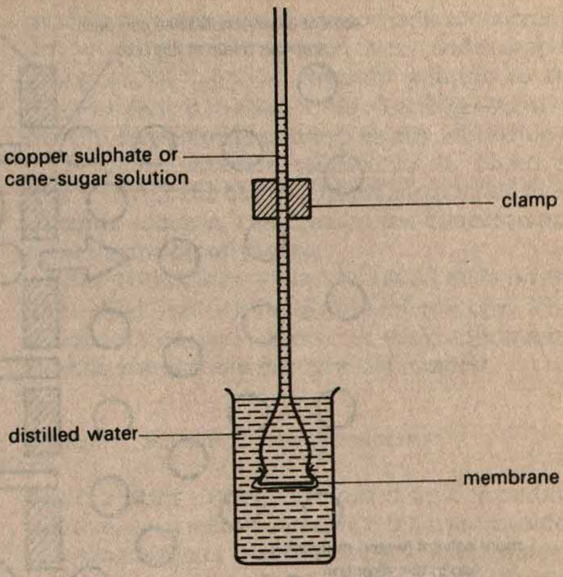


FIG. 18.1 A simple osmometer to demonstrate osmosis

In the above experiment, the water molecules can actually diffuse across the membrane in both directions. However, since the concentration of water molecules is higher in the beaker, more molecules of water enter the funnel than leave it. The quantity of water that diffuses across the semi-permeable membrane into the concentrated sugar solution to make it dilute depends upon the osmotic potential of the concentrated solution. The higher the concentration, the higher the osmotic potential and, hence, the larger the quantity of water (solvent) that can enter it by osmosis.

Activity 2: To show that the protoplasm of a plant cell acts as a semi-permeable membrane.
Some plant cells contain coloured cell sap. For example, if a thin slice of a beetroot is placed in a drop of water on a slide and examined under a microscope, its cells are seen to contain red cell sap. This cell sap is contained in a large vacuole which is surrounded by a thin layer of protoplasm (cytoplasm) with a limiting cell membrane, outside which is the cell wall. If the slide is heated until the water on it boils, the protoplasm around the vacuole will be killed. On now examining the slide you will see the red cell sap escaping from the cells. This observation proves that the protoplasm, while living, acted as a semi-permeable membrane since it did not allow the red cell sap to diffuse out of the cell.

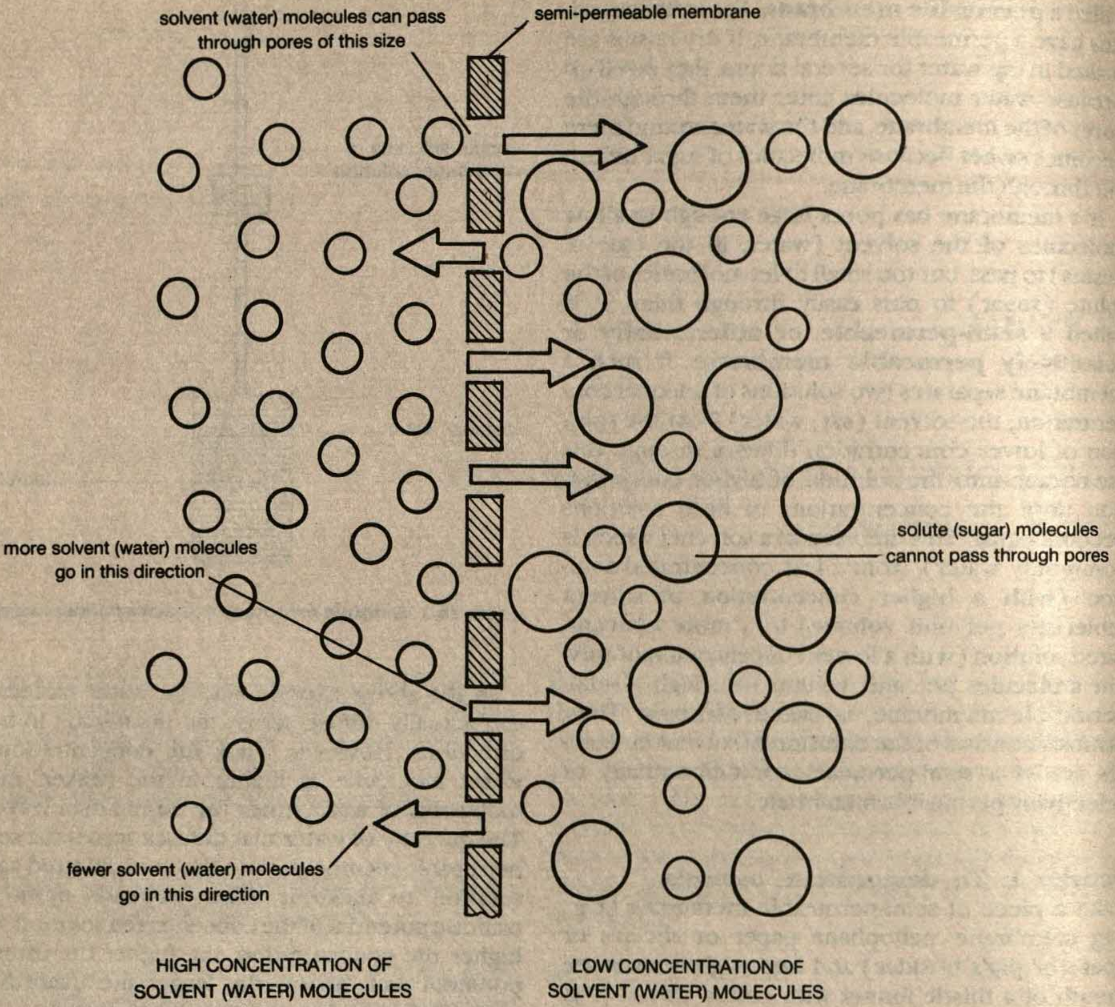

solvent (water) molecules can pass through pores of this size
semi-permeable membrane
solute (sugar) molecules cannot pass through pores
more solvent (water) molecules go in this direction
fewer solvent (water) molecules go in this direction
HIGH CONCENTRATION OF SOLVENT (WATER) MOLECULES
LOW CONCENTRATION OF SOLVENT (WATER) MOLECULES

FIG. 18.2 Possible explanation of osmosis

Can you devise any other experiment to show that protoplasm in plant cells acts as a semi-permeable membrane?

Activity 3: To show that osmosis occurs in living plant cells.

Take three medium-sized potatoes and peel them partly. Boil one of them. Then, carve out cavities in the boiled potato as well as in the two raw potatoes. Set up the three potatoes as shown in the figure [Fig. 18.3], using a well-concentrated sugar solution and distilled water. In the case of potato A (boiled), no change in the levels of water and sugar solution is observed after a certain period of time has passed, i.e., 24 hours. On the other hand, in potato B (raw, with sugar solution in the cavity), the level in the cavity will rise while that in the dish will fall. Finally, in potato C (raw, with water in the cavity), the level in the cavity will fall, while that in the dish will rise.

In the boiled potato, the cells are killed and the semi-permeable membrane is destroyed. No osmosis, therefore, takes place, whereas the living cells in the two unboiled potatoes allow osmosis. How does osmosis take place in the case of potatoes B and C?

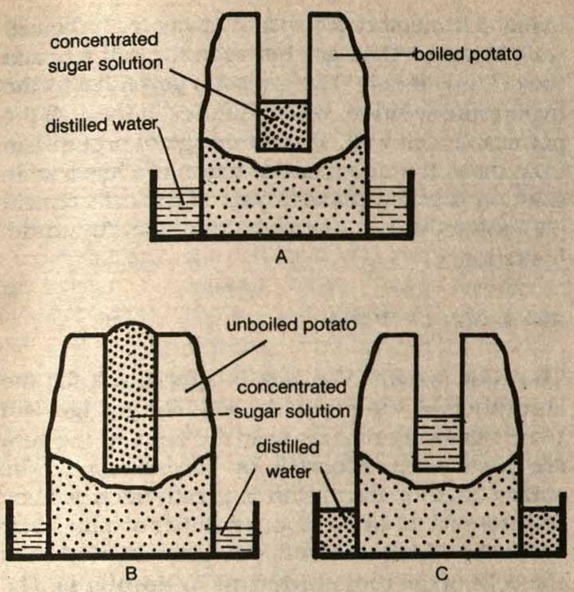


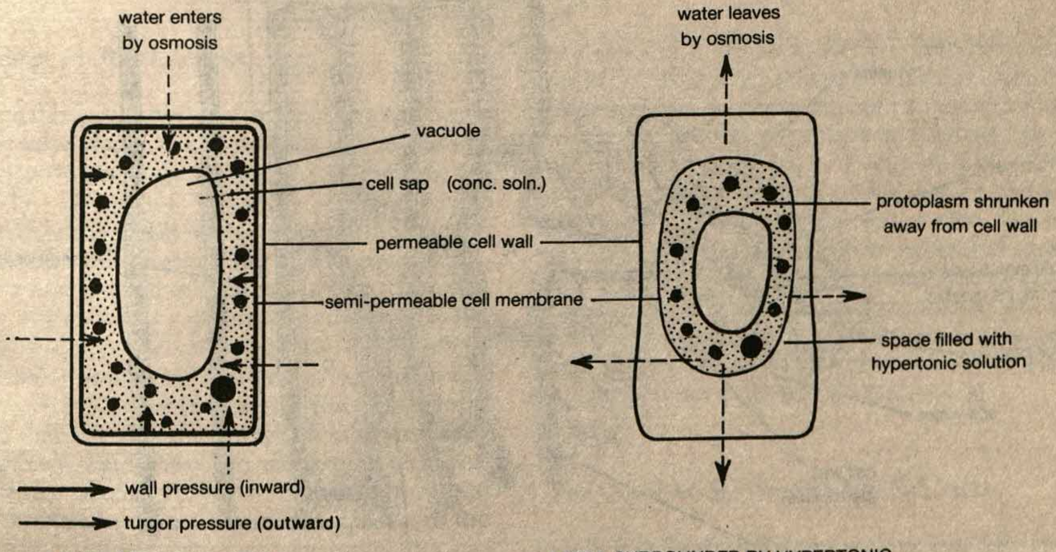
FIG. 18.3 Experimental setup to demonstrate osmosis in living plant cells

Activity 4: To show that osmosis occurs in living animal cells.
Prick one of your fingers with a sterilised lancet or needle to obtain three drops of blood. Distribute them over three clean microscope slides A, B, and C. Add a drop of distilled water to dilute the blood on slide A. In this case, the blood cells are surrounded by a **hypotonic** solution. Next, add a drop of strong (2.0%) sodium chloride solution to the blood on slide B so that the blood cells get surrounded by a **hypertonic** solution. Finally, add a drop of 0.9% sodium chloride solution to the blood on slide C so that the blood cells get surrounded by an **isotonic** solution, i.e., equal to the concentration of salts in the blood plasma.

After 10 minutes, study the blood cells on the three slides under a compound microscope. What differences do you observe in their appearance? How do you account for these differences?

TURGIDITY, FLACCIDITY, AND PLASMOLYSIS

When a plant cell is surrounded by a hypotonic solution, i.e., a solution in which the concentration of solutes is lower than that in the cell sap, water is drawn into its vacuole by osmosis (endosmosis). The vacuole enlarges and pushes the surrounding cytoplasm against the cell wall. The cell membrane also gets pressed against the cell wall. The cell wall, being rigid and slightly elastic, gets stretched and distended. The outward pressure exerted by the cell contents from within, upon the cell wall, is called **turgor pressure**. An opposite and equal inward pressure, called the **wall pressure**, exerted by the cell wall on the cell contents, counteracts the turgor pressure. Eventually, the outward turgor



A CELL SURROUNDED BY
HYPOTONIC SOLUTION (TURGID CELL)

A CELL SURROUNDED BY HYPERTONIC
SOLUTION (PLASMOLYSED CELL)

FIG. 18.4 Turgid cell and plasmolysed cell

pressure becomes equal to the wall pressure and the cell can take in no more water. When this happens, the cell is said to be **turgid**, i.e., fully charged with water.

Turgidity plays an important role in supporting plants and maintaining their shape and form. When the cells in a plant organ press against each other on becoming turgid, turgidity provides mechanical support, particularly to parts such as young leaves and tender shoots (with yet undeveloped mechanical tissues) to hold them firm and upright. The movement of guard cells in controlling the size of the stomata (tiny openings in the epidermis) is also due to turgidity.

When a plant cell is surrounded by a hypertonic solution, i.e., a solution in which the concentration of solutes is higher than that in the cell sap, water is drawn out of the vacuole by osmosis (exosmosis); there is a decrease in turgor pressure and the cell loses its turgidity and stiffness and becomes soft and limp. Such a cell is said to be **flaccid**. When cells of a herbaceous plant lose water, the plant droops or wilts. Due to shortage of water in the soil and also due to the excessive rate of transpiration on a hot sunny day, the plants are often seen wilted. With a continuous loss of water, the protoplasm (with its living cell membrane) shrinks away from the cell wall, leaving a clear gap between the cell wall and the cell membrane. The gap soon gets filled by the hypertonic solution, which diffuses in through the permeable cell wall. This shrinkage of protoplasm from the cell wall under the action of a hypertonic solution is called **plasmolysis**. If the cells remain plasmolysed for a long time, they die due to dehydration.

ABSORPTION OF WATER

The root system of plants is specialised for the absorption of water from the soil. The younger and tender growing regions near the apex of the root are particularly adopted for this function. The surface area of absorption is greatly increased by the presence of an enormous number of unicellular root hairs which are slender outgrowths of some of the cells of the root **epidermis** or **epiblema**. The root hair is surrounded by a permeable cell wall and a semi-permeable cell membrane which encloses a thin layer of cytoplasm. The vacuole inside the root hair cell is filled with cell sap which is an aqueous solution of mineral salts and sugars with a high osmotic potential.

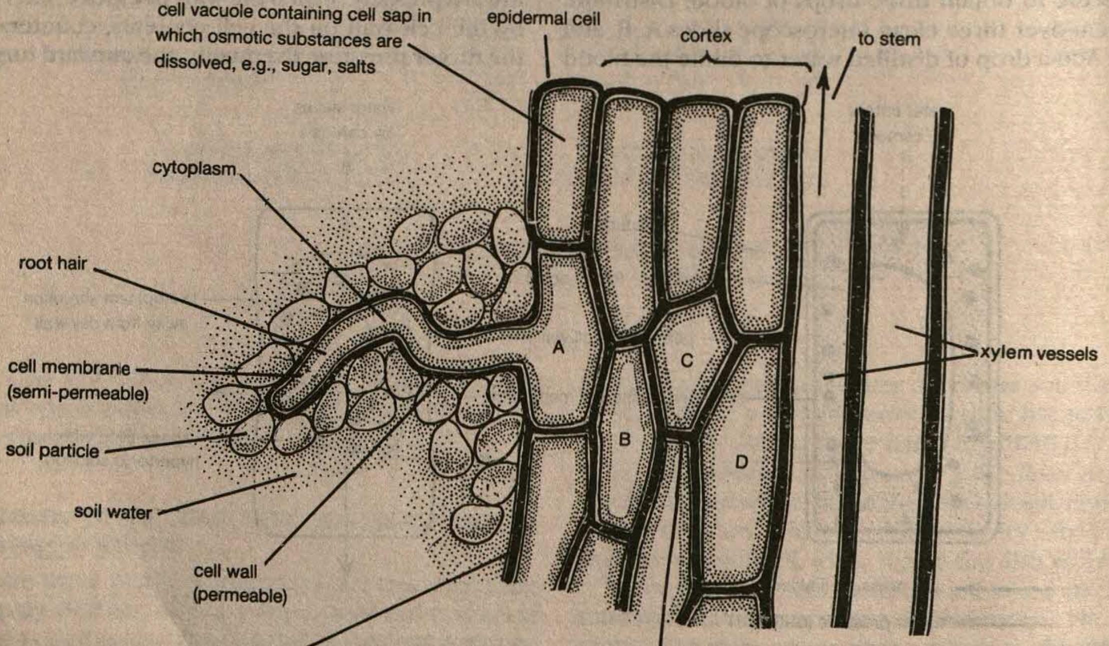

cell vacuole containing cell sap in which osmotic substances are dissolved, e.g., sugar, salts
epidermal cell
cortex
to stem
cytoplasm
root hair
A
C
xylem vessels
cell membrane (semi-permeable)
B
D
soil particle
soil water
cell wall (permeable)
cell wall through which water diffuses
cytoplasm which acts as a semi-permeable membrane

FIG. 18.5 Absorption and conduction in root

A root hair is in direct contact with the water present in the soil outside. This soil water, called **capillary water**, surrounds the soil particles and contains dissolved salts such as sulphates, chlorides, nitrates and phosphates. The osmotic potential of capillary water (a very dilute solution) is much lower than that of the cell sap in the vacuole of the root hair. Since the capillary water in the soil is separated from the cell sap by the cell membrane and a thin cytoplasmic layer (both semi-permeable), water from the soil diffuses into the root hair cell (A) by osmosis (endosmosis). The cell wall, being a permeable membrane, permits molecules of both water and dissolved salts to enter the root hair cell. Due to this osmosis (endosmosis), the cell sap of root hair cells becomes dilute, i.e., its osmotic potential becomes less than that of the cell sap in the cortex cell (B) lying next to the root hair cell. The cell wall, the cell membrane, and the cytoplasm of the cortex cell permit further osmosis, and water molecules diffuse from the root hair cell to the inner cortex cell. In its turn, the osmotic potential of the cell sap in the cortex cell (B) becomes less than that in the next inner cortex cell (C), the water molecules diffuse into inner cortex cells, and finally the water absorbed by the root hair cells reaches the xylem. What will happen in the root hair cell (A) after water has diffused out of it into the inner cortex cell (B)? What will happen in a cortex cell (B) after water has diffused out of it into another inner cortex cell (C)?

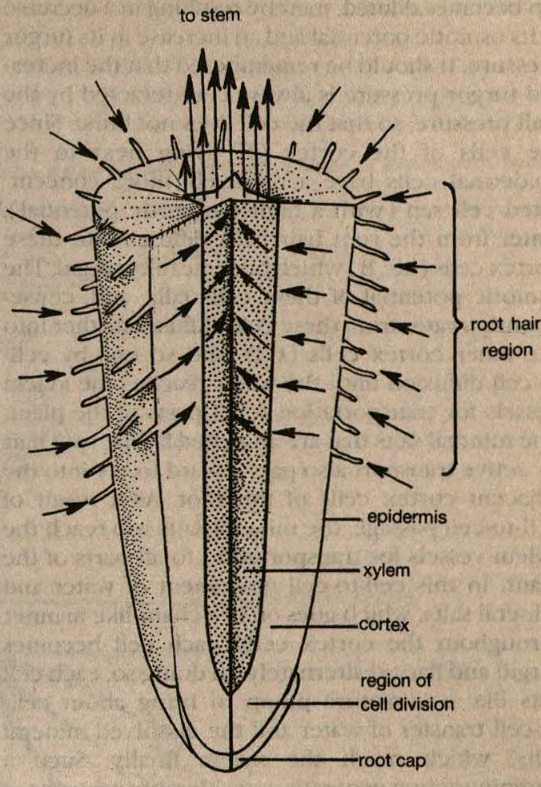


FIG. 18.6 Longitudinal section of a root showing passage of water from the soil to the root.

Absorption of Mineral Salts

In a root hair cell, because the cell wall is a permeable membrane, water as well as the mineral salts dissolved in it are allowed to diffuse into the cell. The cytoplasm being a semi-permeable membrane allows only water, and not the mineral salts, to diffuse into the cell sap in the vacuole.

The concentration of mineral salts in the protoplasm of the root hair cells is higher than that in the capillary water in the soil. Evidently, the dissolved mineral salts cannot diffuse from the capillary water (where their concentration in the cell sap is higher). Yet, the dissolved mineral salts pass from the capillary water into the root hair cells. This happens by means of **active transport**, which transfers substances in a direction opposite to the one in which diffusion does, i.e., the molecules and ions move from a region of lower concentration to a region of higher concentration. To bring about the active transport of dissolved mineral salts from the soil water to the root, the root cells have to use up a lot of the energy released in their metabolism. This energy is released during the respiration of roots in the ground; for this, it is essential that the soil should be well aerated and should contain oxygen between its particles for use by the root hair. If the soil contains too much clay, the root hairs cannot respire and, consequently, cannot obtain cellular energy to absorb mineral salts from the soil. Mineral salts are essential for the life of a plant, and if they are not obtained by the root hairs, the plant dies. It should be noted that mineral salts are absorbed not as molecules but as ions.

Conduction of Water and Mineral Salts

Root hair cells absorb water and mineral salts from the surrounding soil, which they hold within themselves by stretching their elastic cell walls and becoming fully turgid. In such a situation, their cell sap becomes diluted, thereby resulting in a decrease in its osmotic potential and an increase in its turgor pressure. It should be remembered that the increased turgor pressure is always counteracted by the wall pressure, so that the cell does not burst. Since the cells of the cortex (B) lying next to the epidermal cells have a relatively more concentrated cell sap (with a higher osmotic potential), water from the root hair cells diffuses into these cortex cells (i.e., B) which become fully turgid. The osmotic potential of these cells falls, and, consequently, water from these cells diffuses further into the inner cortex cells (C,D, and so on) by cell-to-cell diffusion until the water reaches the xylem vessels for transportation to all parts of the plant. The mineral salts that are absorbed by the root hair by active transport also pass inward freely into the adjacent cortex cells of the root. As a result of cell-to-cell passage, the mineral salts too reach the xylem vessels for transportation to all parts of the plant. In this cell-to-cell movement of water and mineral salts, which goes on in a chain-like manner throughout the cortex cells, each cell becomes turgid and flaccid alternately. In doing so, each cell acts like a miniature pump to bring about cell-to-cell transfer of water and the dissolved mineral salts, which reach the xylem finally. Such a pumping action generates considerable pressure in the root and is sufficient to force water and dissolved mineral salts up the xylem to the height of about 20 metres in the stem against the downward pull of gravity. This pressure exerted by the cells of the cortex to force water and dissolved mineral salts into the xylem is known as **root pressure**. Root pressure may be regarded as the result of all three processes, namely, diffusion, osmosis, and active transport, taking place in the root system.

Activity 5: To demonstrate the rise of water in a stem due to root pressure.

Take a healthy potted plant with strong roots. In the morning (before leaving for school) cut across its main stem, a few centimetres above the soil level in the pot [Fig. 18.7]. Attach a long glass tube to the freshly cut rooted stem by means of a piece of rubber tubing. Support the glass tube vertically (what do you think is the best method of doing this?) and fill it with some coloured water (you may dye tap water with eosin dye). Insert a drop of oil into the glass tube to prevent evaporation of the coloured water and mark its height clearly. Water the plant well. When you return home from school several hours later, observe the level of the coloured water; it would have risen up. How much is the rise? What happens to the colour of the water and why? How does the experiment show the existence of the root pressure? Repeat the same procedure with different species of plants and compare the rise in water levels in the glass tube over the same interval of time. What do your observations indicate?

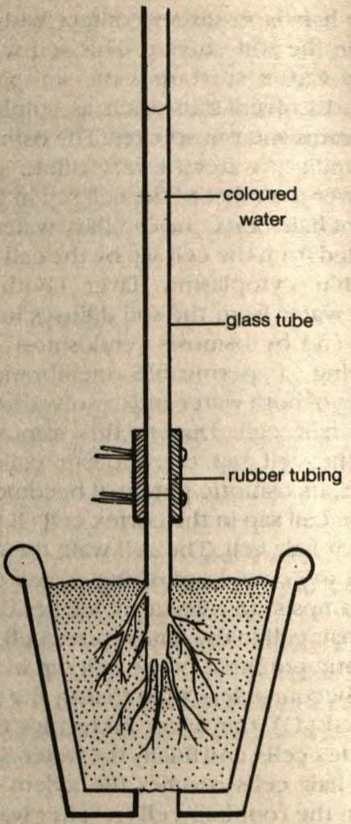


FIG. 18.7 Experimental setup to demonstrate root pressure

SECTION 2: TRANSPIRATION

Often, a plant absorbs more water than it requires, through its root hairs. Most of the excess water evaporates from the surface of the plant in the form of water vapour. **Transpiration** is the process of expelling water from internal tissues in the form of water vapour given off by the aerial parts (leaves, green shoots, branches, etc.) of the plant.

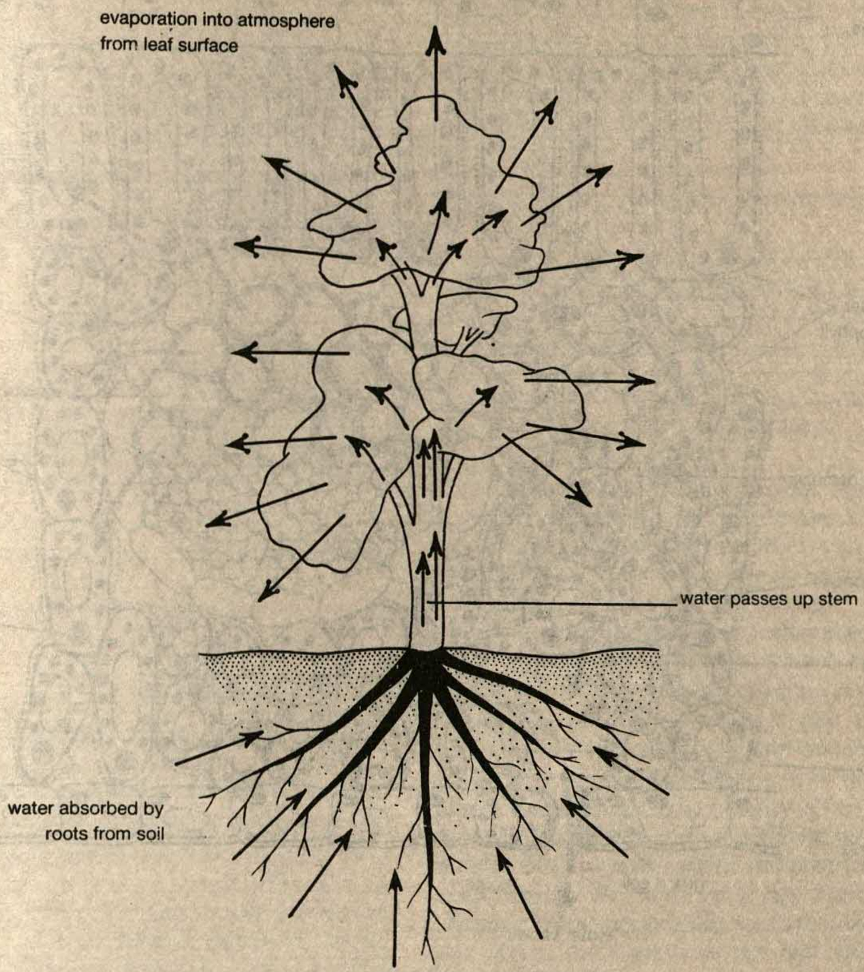

evaporation into atmosphere from leaf surface
water passes up stem
water absorbed by roots from soil

FIG. 18.8 The transpiration stream

The leaf is the main organ of transpiration in a plant. The mesophyll cells of a leaf constantly draw water from the xylem in the veins. They retain a small portion of this water, while the excess portion **diffuses** out through their cell walls. This water forms a thin film covering the mesophyll cells. From there, it evaporates, and the water vapour saturates the air in the intercellular spaces between spongy parenchyma cells. These spaces are connected to the outside atmosphere by means of tiny openings, called **stomata**, in the epidermis. The water vapour diffuses out of the leaf when the stomata open. Diffusion occurs because the intercellular spaces beneath the epidermis are usually saturated with water, while the atmosphere is relatively dry.

THE ACTION OF STOMATA

As already stated, stomata are minute openings in the epidermis on the green aerial parts, especially the leaves, of a plant. Each stoma is surrounded by two bean-shaped, specialised cells called **guard cells**. The guard cells control the opening and closing (and the aperture) of the stomata. The stomata remain open during the day, in the presence of sunlight, and close during the night. This happens because of the special characteristics of guard cells.

Unlike the epidermal cells, guard cells contain **chloroplasts** [Fig. 18.10]. Consequently, they manufacture glucose in the presence of sunlight with the help of chloroplasts. This glucose (or the

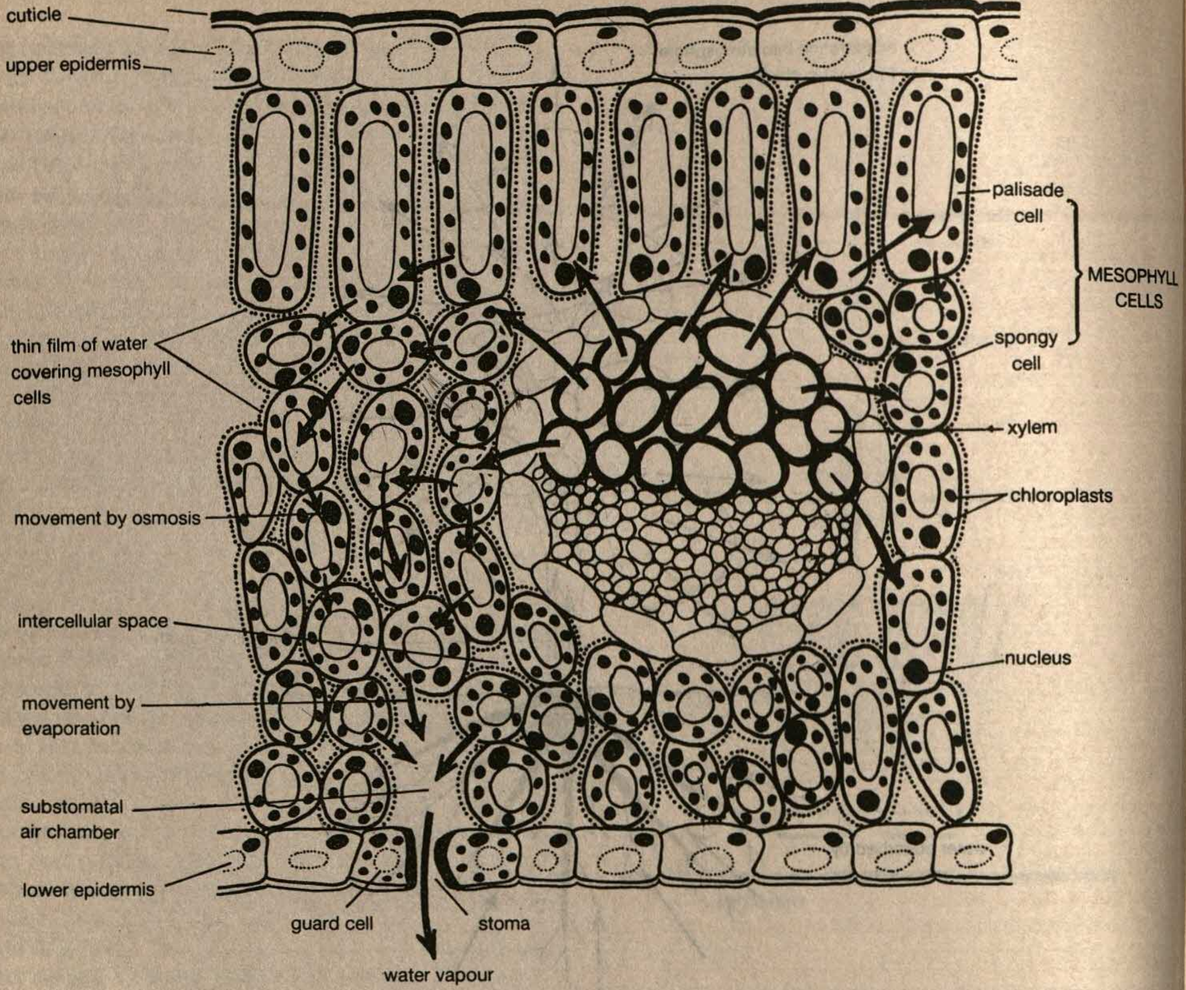


FIG. 18.9 Movement of water through a leaf

active transport of solute ions from the neighbouring epidermal cells) increases the concentration of dissolved substances in the cell sap within the guard cells. When photosynthesis takes place in the guard cells, the concentration of carbon di oxide within them decreases and this lowers the level of carbonic acid within them. Consequently, the stored starch is converted to sugar and the osmotic potential in the guard cells becomes higher than that in the neighbouring epidermal cells. This causes water from the surrounding epidermal cells to enter the guard cells by osmosis. The guard cells begin to swell up and become turgid. Since their inner walls are thicker, the thin outer walls get stretched, and the guard cells curve away from each other. This makes the stomatal

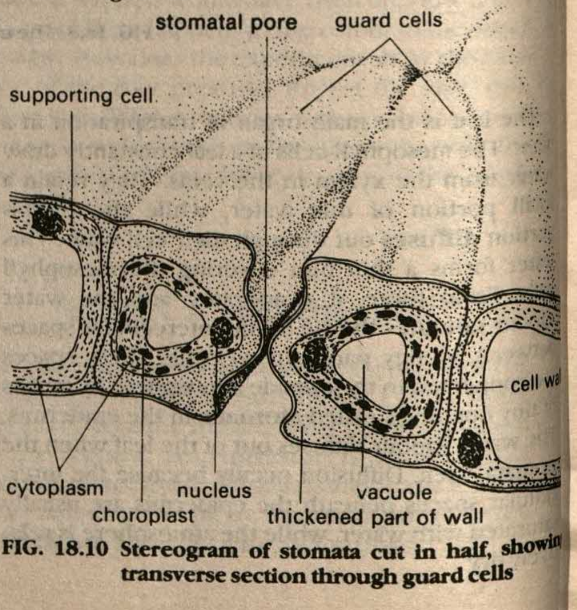
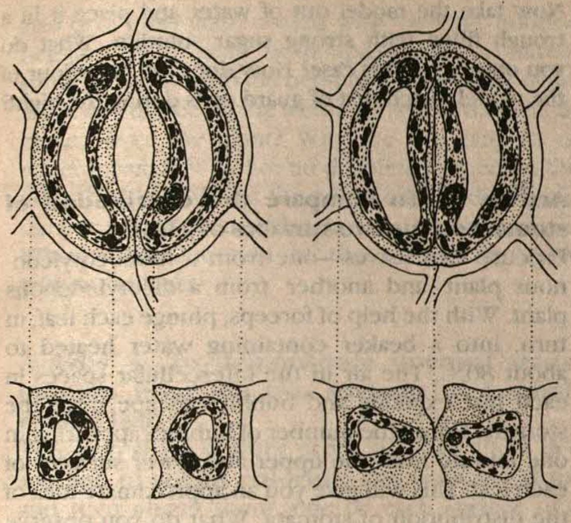


FIG. 18.10 Stereogram of stomata cut in half, showin transverse section through guard cells


pressure high, guard cells turgid, stoma open

pressure low, guard cells flaccid, stoma closed

FIG. 18.11 Action of stomata

opening wider during the day (Fig. 18.11). (This effect can be achieved by inflating a tubular balloon to which a strip of cellotape has been stuck on one side. While it is being inflated, it will bend over towards the cellotape side.) At night the guard cells do not manufacture glucose, and the concentration of dissolved substances in their cell sap falls. Also, at night, when photosynthesis cannot take place, the concentration of carbon dioxide (formed during cell respiration) in the guard cell increases, and this raises the carbonic acid concentration. Consequently, the sugar present in the guard cells is converted to starch, thus making the osmotic potential in the guard cells lower than that in the neighbouring epidermal cells. This causes water from the guard cells to diffuse into the surrounding epidermal cells. This loss of water causes the guard cells to shrink inwards, thereby closing up the stomatal opening between them.

While the stomata are open during the day, they allow water vapour to diffuse out of the leaf into the atmosphere. This constitutes **stomatal transpiration**. The **cuticle** which covers the surface of the leaf ensures that excess transpiration does not take place and thus maintains the balance of water content in the plant. Some amount of water vapour also escapes into the atmosphere through the thin cuticle. This is **cuticular transpiration**. Transpiration also occurs through lenticels (**lenticular transpiration**). Lenticels are small openings, often slightly raised, on woody as well as young stems.

Besides helping in transpiration, the stomata also enable the plant to respire and exchange gases with the atmosphere during photosynthesis.

CONDITIONS AFFECTING TRANSPIRATION

Various environmental conditions affect the rate of loss of water by plants. As a result, it varies from day to day, from hour to hour, and even from minute to minute, according to the changes in the environment. The most important environmental factors which affect the rate of transpiration in a plant are light, humidity, wind, temperature, and atmospheric pressure.

(a) **Light** is the most important factor because it determines the opening and closing of the stomata. As described earlier, transpiration occurs mainly in daylight when the stomata are open and is checked at night when the stomata are closed.

(b) **Humidity** of the air is also very important. When the weather is humid there is considerable moisture in the air and transpiration is slow. On the contrary, when the weather is dry, there is less moisture in the air and transpiration is faster.

(c) **The wind** determines how quickly moisture is removed from the vicinity of the plant. When the wind velocity is high, water vapour is removed quickly from near the plant and transpiration takes place faster. When there is no wind, the water vapour emerging from the stomata tends to remain just above the surface of the leaf, thus checking transpiration.

(d) **Temperature** also affects transpiration; at high temperatures, water evaporates more freely.

(e) **Atmospheric pressure**. The plants growing at high altitudes, where the atmospheric pressure is low, have a high rate of transpiration. Such plants have special adaptations for preventing excessive water loss.

IMPORTANCE OF TRANSPIRATION

Transpiration proves useful to plants in various ways. For instance:

(1) Transpiration enables plants to get rid of the excess water absorbed by their roots.

(2) When water vapour diffuses out of the stomata, a suction force is generated in the plant which helps it to draw up more water and dissolved mineral salts, against the force of gravity. This

transpiration stream is especially useful to tall and large trees. Both the water and the dissolved substances thus drawn upwards are utilised by the plant.

(3) Evaporation during transpiration produces a cooling effect in the plant body. This enables the plant to regulate its temperature.

Activity 1: Observation of stomata.
Peel the epidermis off a thick leaf. Mount a slice of it on a slide with a drop of water. Observe it under a low-power microscope. You will see the epidermal cells, including the guard cells, surrounding the stomata. How do the guard cells differ from the other epidermal cells in appearance?

Activity 2: To prepare a working model of a stoma.
Procure two leak-proof tubes made of cellulose or cellophane paper (or any other semi-permeable material), each about 20 cm long. Fill both of them with a strong sugar solution. Place them side by side and tie them together at the top and the bottom as shown in the figure [Fig. 18.12]. Stick a strip of cellotape on the two surfaces of these leak-proof tubes facing each other. Now, place this model in a trough filled with water. In this state, the model represents two flaccid guard cells. After a few hours, you will see that both the tubes have absorbed water and have become turgid. This absorption is similar to that of guard cells while manufacturing glucose, with the help of the chloroplasts they contain, during the day. The turgid tubes will have moved away from each other, leaving an opening between them.

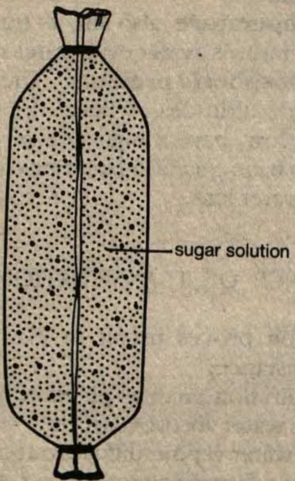


FIG. 18.12 Working model of stoma

Now take the model out of water and place it in a trough filled with strong sugar solution. What do you observe in this case? How does the behaviour of the model match that of guard cells during the night?

Activity 3: To compare the distribution of stomata on the two surfaces of a leaf.
Procure two leaves—one from a monocotyledonous plant and another from a dicotyledonous plant. With the help of forceps, plunge each leaf, in turn, into a beaker containing water heated to about 80°C. The air in the intercellular spaces in each leaf expands and bubbles escape from the stomata. Count the number of bubbles appearing in one minute from the upper and lower surfaces of each leaf. This will give you an approximate idea of the distribution of stomata. What do you observe with respect to the two types of leaves you use? What does this tell you about the distinction between dicotyledonous and monocotyledonous leaves?

Activity 4: To demonstrate that water vapour is given off by plants.
Take a potted plant and securely cover the entire surface of the pot and the soil with a sheet or bag of polythene, leaving only the aerial parts of the plant exposed. Keep the pot on a glass plate coated uniformly with vaseline, and place a bell-jar over it as shown in the figure (Fig. 18.13).

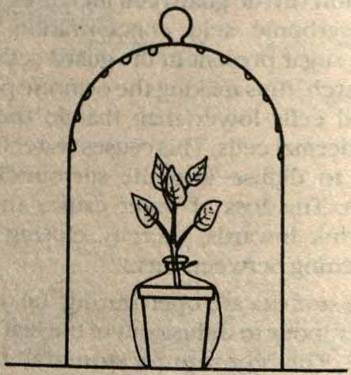


FIG. 18.13 Experimental setup to demonstrate that water is given off by plants

Now, take a pot containing only soil but no plant, and cover it similarly with polythene. Place this pot also on a glass plate coated with vaseline, under a bell-jar. Next, keep both apparatuses in direct sunlight. Study both the bell-jars after an hour or so. What do you see on the inside surface of the bell-jar placed over the plant? Why are the droplets of water formed? Why are no droplets formed on the other bell-jar? Why is the polythene used? What is the purpose of coating the glass plate with vaseline? What is the function of the second apparatus without a plant?

Activity 5: To demonstrate unequal transpiration from the two surfaces of a dorsiventral leaf.

Take two strips of filter paper and soak them in a solution of **cobalt chloride**. Dry both the strips and then attach them, one to each surface of a healthy leaf of a potted plant, with the help of cellotape or glass slides. The strips of paper must be covered entirely by cellotape or glass slides in order to prevent contact between atmospheric moisture and the cobalt chloride.

Cobalt chloride paper is deep blue in colour when dry, but turns pink when moistened. When the potted plant is placed in sunlight, you will observe that the cobalt chloride strip attached to the lower surface of the leaf turns pink within a few minutes, while that attached to the upper surface remains blue for a longer time. This evidently shows that transpiration occurs at a much faster rate on the ventral side of the leaf than on the dorsal side. What does this experiment tell you about the distribution of stomata on the two surfaces of a dorsiventral leaf?

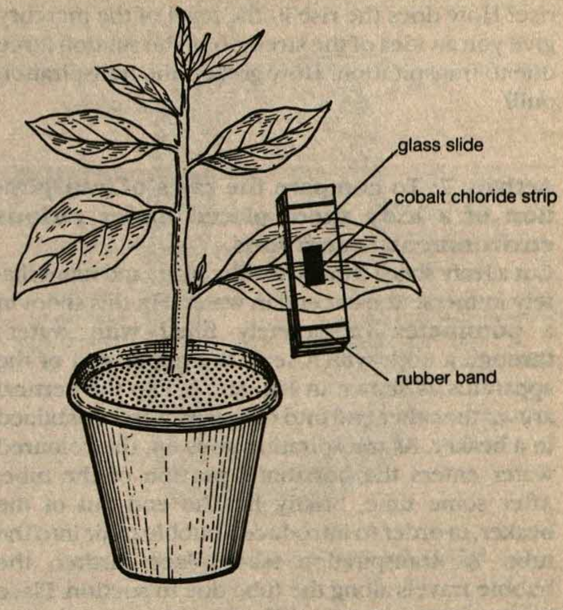


FIG. 18.14 Experimental setup to demonstrate unequal transpiration

Activity 6: To demonstrate transpiration pull.

Set up the apparatus shown in Fig. 18. 15. Make sure that the apparatus is full of water and contains no air. Cut the end of the shoot under water to prevent air from entering the wood vessels. In order not to damage the shoot as it is pushed through the cork, pass a cork borer of a slightly bigger size than the shoot through the hole in the cork *from below upwards*. Slide the shoot into the cork borer from above, and then gently remove the cork borer. Fill the tube with water, cover the open end with a finger and turn the whole tube upside down. Place the open end below the level of some mercury taken in a container, and remove the finger. Place the whole apparatus near an open window. After a few hours, the mercury is seen to have risen to a certain height in the tube. Why does the mercury

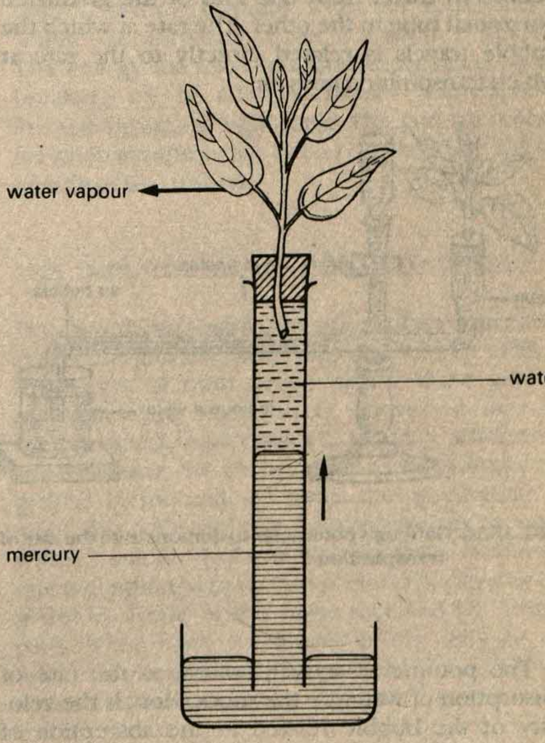


FIG. 18.15 Experimental setup to demonstrate transpiration pull

rise? How does the rise in the level of the mercury give you an idea of the strength of the suction force due to transpiration? How great is the transpiration pull?

Activity 7: To compare the rates of transpiration of a leafy shoot placed under various environmental conditions.

Cut a leafy shoot from a healthy plant and immediately immerse the cut end in water. Fix this shoot in a **potometer** (completely filled with water) through a cork which seals the upper end of the apparatus as shown in Fig. 18.16. Dip the vertical arm of the other end into coloured water contained in a beaker. As transpiration goes on, the coloured water enters the horizontal portion of the tube. After some time, briefly lift the end out of the beaker, in order to introduce a bubble of air into the tube. As transpiration takes place further, the bubble travels along the tube due to suction. Place such a potometer in different environments; for example, in open air and sunlight, in a dark room, under a fan, and in a warm room without a fan. For each environment, note the time taken by the bubble to travel from one end of the graduated horizontal tube to the other. The rate at which the bubble travels is related directly to the rate at which transpiration goes on.

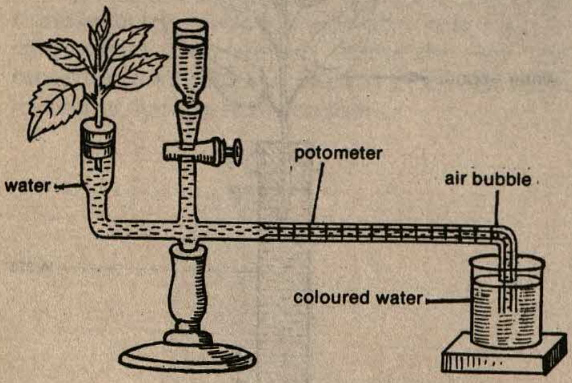


FIG. 18.16 Ganong's potometer to demonstrate the rate of transpiration

The potometer actually measures the rate of absorption of water by the shoot. How is the velocity of the bubble related to the absorption of water? What assumption do we make about the relationship between the rate of absorption of water and the rate of transpiration, when we take the velocity of the bubble to give us a direct measure of the rate of transpiration?

SECTION 3: ASCENT OF SAP

The solution of mineral salts absorbed by the root hairs consists of (i) water, (ii) ions of potassium, magnesium, iron, etc., and (iii) sulphates, phosphates, nitrates, etc. This solution is called **sap**. It enters the root by osmosis and active transport, the mineral salts being absorbed as ions and not as molecules in the latter process. The sap reaches the xylem vessels in the root and, from there, it is transported to the aerial parts of the plant. Transportation is achieved with the help of certain physical forces acting within the plant. Continual evaporation of water from the leaves to the atmosphere leads to an increase in the osmotic potential in the mesophyll cells which draw water from the ends of xylem vessels in the leaves. Thus, water molecules from the inner regions of the leaf replace those that have been lost to the atmosphere. As a result of cohesion, these molecules tend to pull other water molecules towards the surface and so on. Thus, a strong suction force is generated as a consequence of transpiration. Due to a strong cohesive force between water molecules, the sap contained in the xylem vessels forms a long continuous column extending from the root to the leaf without air bubbles being present anywhere in it. The strong suction force generated as a consequence of transpiration pulls up the long continuous column of sap like a rope which can be hauled up from the roof of a building. Thus, the sap continuously travels upward along the xylem, pushed up to a certain extent (a maximum of about 20 metres) by root pressure and then pulled up further by the strong suction due to transpiration, thus providing the green parts of tall plants with materials required for their vital activities.

SECTION 4: PHOTOSYNTHESIS

Photosynthesis is the process by which green plants manufacture the carbohydrate food that they require with the help of carbon dioxide and water. In land plants, the water is absorbed from the soil by the roots and the carbon dioxide from the air through the stomata. The energy for photosynthesis is obtained from sunlight, which is absorbed by chlorophyll. Besides, chlorophyll also acts as a biocatalyst in this process where oxygen is given off as a byproduct.

The process of photosynthesis may be represented by a simple chemical equation:

$$\underset{\text{(carbon dioxide)}}{6CO_2} + \underset{\text{(water)}}{12H_2O} \xrightarrow[\text{absorbed by chlorophyll}]{\text{energy from sunlight}} \underset{\text{(glucose)}}{C_6H_{12}O_6} + \underset{\text{(water)}}{H_2O} + \underset{\text{(oxygen)}}{6O_2}$$

From this equation, the entire process appears to be simple, but, in reality, it is an extremely complex chain of chemical reactions involving several enzyme systems and intermediate products.

Photosynthesis takes place mainly in the leaves, though any green part of the plant can carry it out. Leaves of green plants are specially adapted to carry out photosynthesis within them because of the following reasons:

(a) They have a broad, flat shape and offer a large surface area for absorption of sunlight and carbon dioxide.

(b) They are mostly thin, so that the distances across which carbon dioxide has to diffuse so as to reach the mesophyll cells from the stomata are very small.

(c) They have numerous stomata for the efficient exchange of gases.

(d) They have large intercellular spaces for the easy passage of gases.

(e) They have numerous chloroplasts in the mesophyll cells—especially palisade cells. (Chloroplasts are the plastids containing chlorophyll and are the actual sites where photosynthesis takes place.)

(f) They have a vast network of veins for the efficient supply of water to the photosynthesising cells.

Water absorbed from the soil by the root hairs reaches the leaves through the xylem. This water is drawn into the mesophyll cells from the nearest vein or veinlet. Excess water in the mesophyll cells diffuses out and forms a thin film around them. Carbon dioxide from the atmosphere diffuses into the intercellular spaces around the mesophyll cells through the stomata and dissolves in the thin film of water. Carbon dioxide further diffuses into the mesophyll cells through their permeable cell walls and travels to the chloroplasts in the cytoplasm.

The process of photosynthesis consists of two stages: light and dark. In the light stage, chlorophyll absorbs the radiant energy of sunlight and converts it to chemical energy. This is then used for photochemical splitting of water molecules into oxygen and hydrogen atoms. This process is known as **photolysis**. Oxygen is given off as oxygen gas, while hydrogen atoms are used in the dark stage to reduce carbon dioxide with the formation of simple carbohydrate molecules such as glucose. The energy for this reduction is provided by the breaking up of ATP (adenosine triphosphate) formed during the light stage. This general scheme for photosynthesis has been confirmed by the use of radioactive tracers.

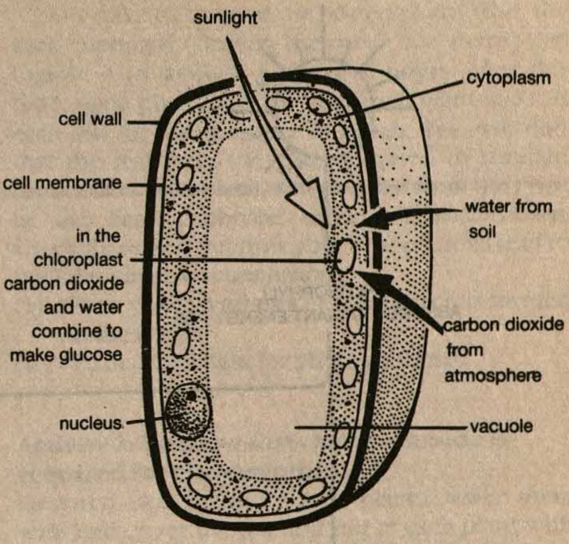

sunlight
cytoplasm
cell wall
cell membrane
water from soil
in the chloroplast carbon dioxide and water combine to make glucose
carbon dioxide from atmosphere
nucleus
vacuole

FIG. 18.17 **Photosynthesis in a palisade cell**

THE IMPORTANCE OF PHOTOSYNTHESIS

Photosynthesis enables the leaves of green plants to synthesise glucose molecules within their cells. In the leaves of most green plants, these glucose molecules are immediately converted into insoluble starch molecules $(C_6H_{10}O_5)_n$ where n is some integer. Starch is also a carbohydrate, and gathers in the cells of leaves during daytime. At night, this collected starch is reconverted to sugar, which is soluble. In this soluble form, the carbohydrate is conducted to various parts of the plant by the **phloem**. Some of the sugar received by various parts of the plant is oxidised in the cells for the release of energy during respiration. The rest of the sugar is in excess of the respiratory requirement and is stored in various storage organs. These organs reconvert the soluble sugar into insoluble starch, which is again stored for future use.

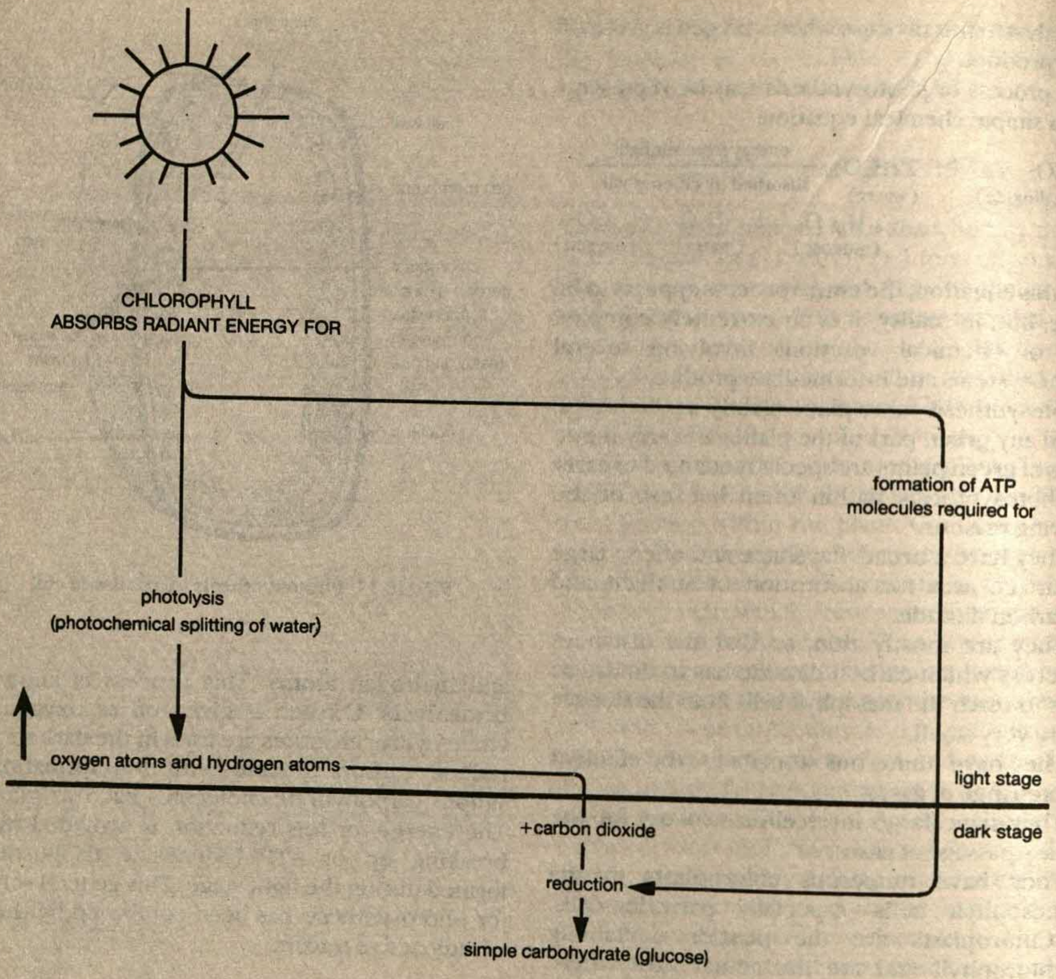

CHLOROPHYLL
ABSORBS RADIANT ENERGY FOR
formation of ATP
molecules required for
photolysis
(photochemical splitting of water)
oxygen atoms and hydrogen atoms
light stage
dark stage
+carbon dioxide
reduction
simple carbohydrate (glucose)

FIG. 18.18 Summary of events in photosynthesis

The various steps occurring during photosynthesis produce intermediate compounds which have their own importance. One of the most important of these compounds, and the first stable one, is PGA (phosphoglyceric acid). From PGA, different types of carbohydrates, fats, and proteins can eventually be formed, depending upon the requirements of the plant.

Photosynthesis is vital not only for plants but also for animals, since this process produces the basic organic substances,required by all living organisms for their nourishment. It is also essential because it releases oxygen into the atmosphere, and most living organisms require oxygen for respiration.

Activity 1: To show that starch is formed during photosynthesis and that light is essential for photosynthesis.

Place two healthy potted plants in a dark cupboard, which is not air-tight. After 48 hours, pluck one leaf from each plant and test each of them as follows:

Dip the leaf into boiling water for half a minute. This kills the protoplasm in the cells of the leaf. Now, boil the leaf in either alcohol or acetone (placed inside a test tube in a water bath) until the leaf becomes colourless. This happens because the leaf loses all its chlorophyll. Remove the leaf from the alcohol or acetone and again place it in warm water for a few minutes until its lamina becomes

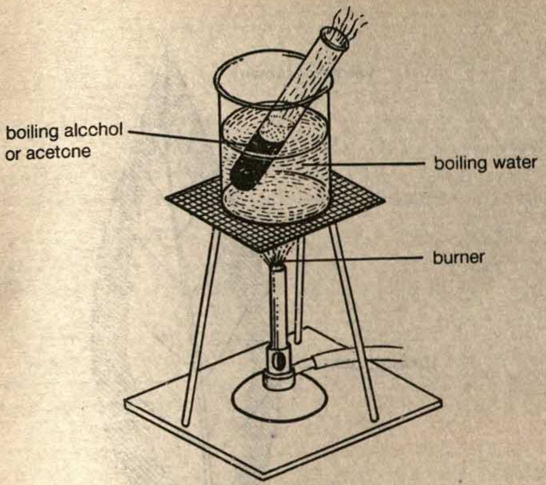


FIG. 18.19 Removal of chlorophyll from a leaf

soft. Take the leaf out of water and spread it flat on a glazed tile. Pour a few drops of weak iodine solution on the leaf and watch the change in colour. If the leaf turns blue-black, it still contains some starch, even after having been kept in the dark cupboard for 48 hours. On the other hand, if the leaf turns yellowish-brown then it has been destarched (has lost all its starch). The loss of starch takes place because, in the dark cupboard, the leaf cannot manufacture fresh glucose and so uses up all its stored starch. If the leaf turns yellowish-brown, what do you learn about the requirement of light and the manufacture of starch during photosynthesis?

Now, take out one of the potted plants from the dark cupboard (leaving the other one there) and expose it to sunlight for several hours. After this time, again pluck one leaf from each plant and test each leaf for the presence of starch. You will find that the leaf from the plant exposed to sunlight turns a dark blue-black, whereas that from the plant in the dark cupboard turns yellowish-brown. Carefully reason out how your observations lead to the following two conclusions:

(i) When photosynthesis occurs, starch is formed in the leaves.
(ii) Plants need light for photosynthesis.

Activity 2: To show that carbon dioxide is required for photosynthesis.

Destarch two healthy potted plants, water them well, and cover the pot and soil of each plant with polythene to prevent the respiratory activities of the soil organisms from interfering with the experiment. Now, place the two potted plants under bell-jars, as shown in the figure [Fig. 18.20]. Make the apparatus air-tight by applying vaseline along the margin of each bell-jar. Inside one bell-jar place a dish containing soda lime and also place soda lime in the bulb of that bell-jar. Cause a stream of air to pass through each bell-jar. The soda lime in the bulb absorbs of the carbon dioxide in the air passing over the potted plant. The plant in the other bell-jar receives air containing carbon dioxide. Now, place both apparatuses in sunlight for a few hours. Later, pluck one leaf from each plant and test both for the presence of starch with a weak solution of iodine. What do you observe? How do your observations

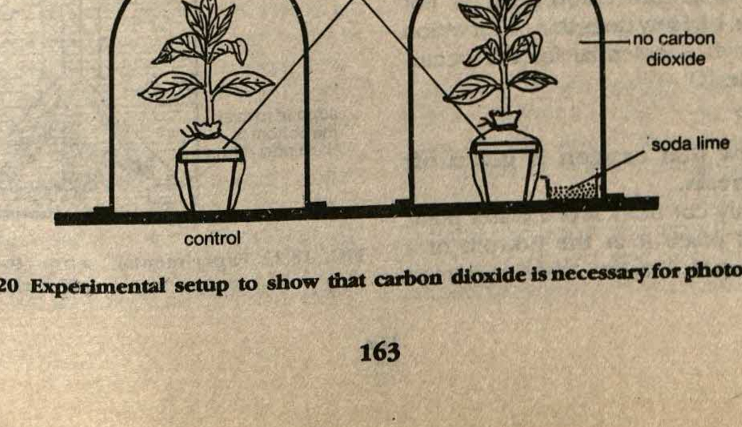


FIG. 18.20 Experimental setup to show that carbon dioxide is necessary for photosynthesis

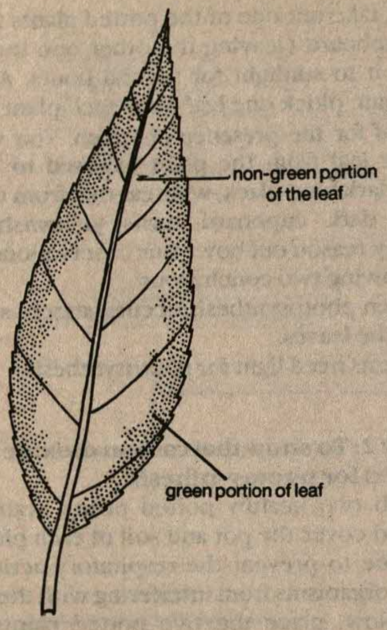


FIG. 18.21(a) Drawing of the leaf

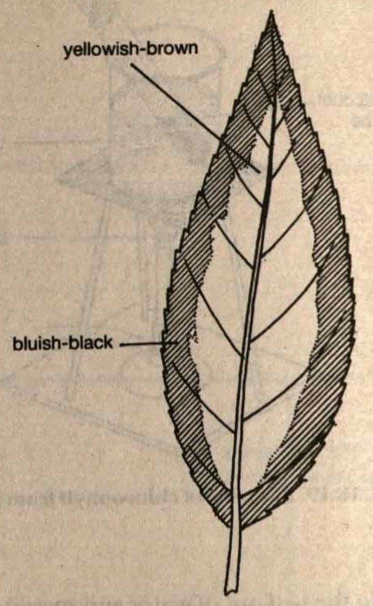


FIG. 18.21(b) Same leaf tested for starch

about the starch content of the leaves demonstrate that carbon dioxide is essential for photosynthesis?

Activity: 3: To show that chlorophyll is necessary for photosynthesis.

Destarch a healthy, potted garden croton plant with variegated leaves. (Since chlorophyll cannot be removed from a leaf without killing it, a plant with variegated leaves must be used for this activity.) The leaves of this plant do not have chlorophyll distributed over their entire laminas; it is present in patches only. Test one or two of its leaves for starch. Expose the plant to sunlight for about four hours. Pluck one of the leaves and make a sketch to show the green and non-green portions on it. Test this leaf for starch and compare it with its sketch (which you have just made). You will observe that the leaf turns bluish-black wherever chlorophyll is not present [Figs. 18.21a, b]. How does this observation show that chlorophyll is essential for the occurrence of photosynthesis?

Activity 4: To show that oxygen is given off during photosynthesis.

Obtain a small, freshly cut branch of a water plant (e.g., *Hydrilla*) and place it at the bottom of a beaker full of pond water. Invert a short-stemmed funnel over the branch in the beaker. Next, invert a test tube also containing pond water over the stem of the funnel as shown in the figure [Fig. 18.22]. Add a pinch of sodium bicarbonate to the water and let the apparatus stand in sunlight, raising the bottom of the funnel to allow free circulation of water. Within a few minutes, you will observe bubbles arising from the cut ends of the branch of the water

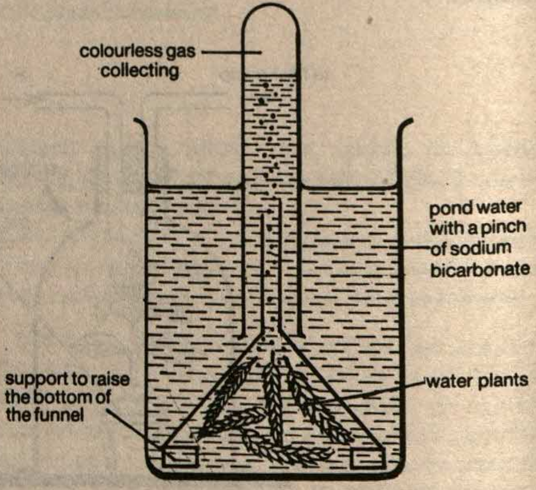

colourless gas collecting
pond water with a pinch of sodium bicarbonate
support to raise the bottom of the funnel
water plants

FIG. 18.22 Experimental setup to demonstrate that oxygen is given off during photosynthesis

plant, and these bubbles will collect in the inverted test tube. When a sufficient amount of gas has collected, remove the test tube from the apparatus and insert a glowing splint into it. What happens to the glowing splint? Which gas has been collected in the test tube? Why has sodium bicarbonate been added to the pond water? Explain how you can conclude from these observations that oxygen is released during photosynthesis. How would you set up a control experiment? Why are only water plants used in this experiment? Why is it necessary to fill up the beaker completely with pond water before inverting the test tube full of pond water over the stem of the funnel?

SECTION 5: RESPIRATION

Respiration occurs in the cytoplasm of all living cells. It is essentially a chemical process which releases the energy required by plants and animals to perform activities necessary for their existence. In plants, these life activities are often not perceptible from the outside, whereas in animals they usually are (as in physical movement). Nevertheless, both plants and animals use up the energy released during respiration. This energy is obtained in plant and animal cells by the oxidation of carbohydrates, fats, proteins, etc., which are present in the cytoplasm. All these substances contain stored chemical energy which is released during their oxidation. Mostly, simple carbohydrates like glucose are oxidised. The process of oxidation of these food substances (mostly glucose) which takes place in the mitochondria in a cell is known as respiration, and the chemical reaction which occurs may be represented by a simple equation:

$$C_6H_{12}O_6 \text{ (with stored energy)} + 6O_2 \xrightarrow[\text{living cells}]{\text{in all}} 6CO_2 + 6H_2O + \text{released energy } 2830 \text{ kJ}$$

However, the actual process of the oxidation of glucose is not as simple as this equation makes it out to be. It is a complicated series of chemical reactions controlled by enzymes which release energy at every stage. It is this entire process which is known as respiration. This is a chemical process which takes place in the cells of an organism and is known as **internal** or **tissue respiration**. This process is not to be confused with **breathing** or **external respiration**, which is simply a physical process by which oxygen from the environment enters an organism and water vapour and carbon dioxide are released into the environment. Further, no enzymes control breathing and no energy is released during this process.

All living cells in a plant, wherever the plant may be and wherever the cells may be located within the plant, undergo respiration constantly in order to obtain energy for their life activities. They constantly take in oxygen and give out carbon dioxide and water. The growing organs of a plant, such as flower and vegetative buds, and the tips of root branches and hairs, respire very actively, whereas adult organs, like the stem, respire comparatively slowly.

Oxidation of food substances, however, does not directly supply energy for the immediate needs of a living organism. The immediate source of energy for all life activities is a phosphate compound called ATP (adenosine triphosphate)—a chain of three phosphate groups linked to adenosine. (ATP=adenosine—P—P~P). In the presence of suitable enzymes in the cells, ATP changes to ADP (adenosine diphosphate) with the detachment of the terminal phosphate bond and release of a relatively large amount of energy (34 kJ/mole), i.e.,

$$\text{ATP} \rightarrow \text{ADP} + \text{P} + \text{released energy (34 kJ)}.$$

Some of this energy is lost as heat and a major proportion of it is used for the cell activities.

ATP is the universal supplier of energy for all life activities. As such, it must always be available in a cell as a ready source of energy as and when required. The purpose of the oxidation of food substances in the living cells is to produce a continuous stream of energy required for the synthesis of ATP. This synthesis involves attaching a phosphate group to ADP (the reverse of what happens when ATP changes to ADP)—a chemical reaction which requires as much energy as is produced when ATP changes to ADP:

$$\text{ADP} + \text{P} + \text{energy from oxidation of food substances} \rightarrow \text{ATP}.$$

Sugars contain energy for ATP synthesis in a readily available stored form which can be easily drawn upon when the occasion arises. Starch, glycogen, and fats contain energy for ATP synthesis in a less readily available stored form; while cell proteins represent the remotest source of energy for this purpose and are used only when no carbohydrates or fats are available for oxidation.

In plants there are no special organs for the exchange of gases like gills in fishes and lungs in human beings. The entry and exit of gases take place through the stomata in leaves and, in bushes and trees, through the **lenticels** (small raised pores developed in woody stems) as well. Oxygen diffuses through the stomata and lenticels into the small air spaces present throughout the plant body. The network of air spaces is particularly well developed in the leaves of a plant. From these intercellular air spaces, oxygen first diffuses into the thin film of water surrounding the cells and then into the cells where the concentration of oxygen is less.

Respiration takes place both in the presence and in the absence of sunlight. In the presence of sunlight, the stomata are open; photosynthesis is in progress, and the oxygen thereby produced is used for respiration. And the carbon dioxide produced during respiration is used in photosynthesis. Any excess gases are taken in (if required) or expelled through the open stomata.

In the absence of sunlight, the stomata are closed. There is less oxygen in the air spaces between cells than in the atmosphere outside the plant.As a result, oxygen diffuses into the plant through the lenticels of the stem, which always remain open. To a certain extent, oxygen diffuses in through the walls of the epidermal cells also. Similarly, carbon dioxide produced during respiration at night diffuses out of the lenticels as well as through epidermal cells.

In the case of the majority of living plants, free oxygen from the atmosphere is used for respiration. This results in the **complete** oxidation of food substances and in the release of a considerable amount of energy. This type of respiration occurs in living organisms when enough oxygen is freely available, and is called **aerobic respiration**. However, some bacteria and fungi (and some intestinal worms living in oxygen-deficient environments) can respire in the absence of free oxygen. This type of respiration is called **anaerobic respiration**. It results in an **incomplete** oxidation of food substances and in the release of a much smaller amount of energy. In anaerobic respiration, glucose is only partially oxidised. Instead of being oxidised to carbon dioxide and water, it is converted either into alcohol (in plants) or into lactic acid (in animals). The respective equations are as follows:

$$C_6H_{12}O_6 \xrightarrow{\text{in plants}} \underset{\text{(ethyl alcohol)}}{2CH_3CH_2OH} + 2CO_2 + 210\ \text{kJ}$$

$$C_6H_{12}O_6 \xrightarrow{\text{in animals}} \underset{\text{(lactic acid)}}{2CH_3CH(OH)COOH} + 150\ \text{kJ}$$

In the absence of free oxygen, many tissues of higher plants, stored seeds, and fleshy fruits can respire anaerobically for a limited period of time, with the release of an amount of energy just sufficient to maintain the activity in the protoplasm of their cells.

Activity 1: To show that carbon dioxide is given off during respiration.

Set up four flasks A, B, C, and D as shown in Fig. 18.23. Each flask is fitted with an air-tight cork having two holes through which delivery tubes pass. The delivery tubes are connected with rubber tubing, as shown in the figure. Flask A contains caustic soda solution and flasks B and D lime water. Flask C contains germinating pea seeds soaked in water or a few opening flower buds, or even a freshly cut shoot immersed in water contained in a

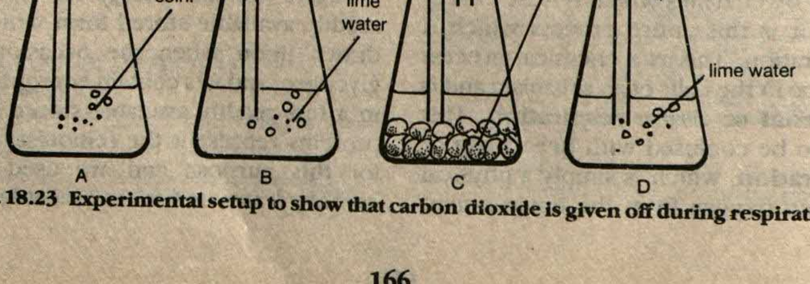


FIG. 18.23 Experimental setup to show that carbon dioxide is given off during respiration

small test tube. A filter pump is used to draw air through the entire apparatus for some time. The caustic soda solution in flask A will absorb any carbon dioxide present in the air passing through it, and so the lime water in flask B will not turn milky. After air has been drawn continuously through the entire apparatus for a few hours, you will observe that whereas the lime water in flask B has remained clear, the lime water in flask D has turned milky. This shows that flask B receives air not containing carbon dioxide from flask C. Where does carbon dioxide evolve in flask C? If flask C contains some green living plant material, or a green shoot, the flask should be covered with light-proof paper or cloth. Why? How will you show that carbon dioxide is evolved in flask C by respiration and not by photosynthesis?

Activity 2: To show that oxygen is used up during respiration.

In a conical flask, place some soaked, fully swollen germinating pea seeds and a small test tube containing caustic soda [Fig. 18. 24]. Connect a delivery tube to the conical flask by means of a cork, and dip the other end of the tube in water contained in a beaker. Make all the connections air-tight. Then, set up an identical control apparatus, but do not place germinating pea seeds and caustic soda in the conical flask. Mark the level of water in the delivery tube. Cover both the apparatuses with light-proof paper or cloth and keep them aside for some time.

After a while you will see that in the apparatus containing germinating pea seeds, some water from the beaker has risen up the delivery tube. This shows that some amount of gas has been removed from within the conical flask. Since the apparatus is air-tight, the gas must have been used up by the germinating pea seeds. We can say this because water does not rise up the delivery tube in the control experiment. If you now plunge a glowing or burning splint into the flask containing the germinating pea seeds, you will observe that the splint does not glow or burn further and is quickly extinguished. This shows that the experimental flask does not contain oxygen. Obviously, the oxygen has been consumed.

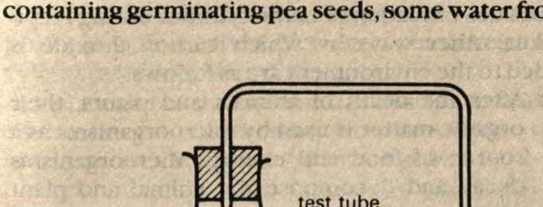


FIG. 18.24 Experimental setup to demonstrate that oxygen is consumed during respiration

On the other hand, if you plunge a glowing splint into the flask in the control apparatus, it will continue to glow, showing that oxygen is still present in that flask. What conclusion can you draw from these observations regarding the role of oxygen in the respiration of germinating pea seeds? Why is the rise of water in the experimental delivery tube an important observation? What is the exact role of the caustic soda solution?

Activity 3: To show that heat is produced during respiration.

Soak some seeds in water. When they begin germinating, take them out of the water and place them in a thermos flask [Fig. 18. 25]. Insert a laboratory thermometer into the flask and plug the mouth of the flask with cotton wool. Take some more seeds and kill them by boiling in water. Cool the seeds and treat them with formalin to prevent

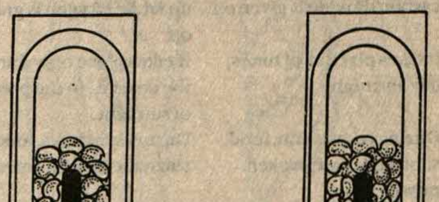


FIG. 18.25 Experimental setup to demonstrate that heat is released during respiration

decay by bacteria. Place them now in another flask. Insert a thermometer into this flask also and seal it with cotton wool. This will act as the control apparatus.

Invert the two thermos flasks and leave them aside, and note down the temperatures registered on both thermometers at the beginning, again after 24 hours, and then again after 48 hours. What do you observe with regard to the temperature in the thermos flask containing germinating seeds, as compared to that in the control flask? Why does the rise in temperature occur? What do you conclude from these observations? Perform the same experiment with seeds of five different plants and formulate a table of temperatures recorded (1) at the beginning, (2) after 24 hours, and (3) after 48 hours. What does this table tell you about the amount of heat given off during respiration in the germinating seeds of different plants? Why is it necessary to invert the flasks?

We now present a table (Table 18.1) to bring out the major differences between respiration and photosynthesis.

TABLE 18.1 COMPARISON BETWEEN RESPIRATION AND PHOTOSYNTHESIS

S.No.	RESPIRATION	PHOTOSYNTHESIS
1.	It takes place in plants as well as animals.	It takes place only in green plants.
2.	It takes place in all living cells of a plant.	It takes place only in plant cells containing chloroplasts.
3.	Oxygen is used up while carbon dioxide is given off.	Carbon dioxide is used up while oxygen is given off.
4.	It takes place at all times, day and night.	It takes place only during the day, i.e., in the presence of sunlight.
5.	During respiration, food substances are broken down.	During synthesis, food substances are formed.
6.	During respiration, energy is released during the breakdown of food substances.	During photosynthesis, energy is stored in the food substances that are produced.
7.	It results in a loss of dry weight of the plant because food substances are broken down.	It results in an increase of dry weight of the plant because food substances are produced.

THE CARBON CYCLE IN NATURE

During photosynthesis, green plants all over the world use up millions of tons of carbon dioxide from their environments—either from the atmosphere or from the water in which they live—and give out oxygen. It is likely that the environment may become poorer in carbon dioxide and richer in oxygen. On the other hand, during respiration, all living organisms use oxygen from their environment and give out carbon dioxide. It is likely, again, that the environment may become poorer in oxygen and richer in carbon dioxide. However, the average carbon dioxide and oxygen contents in the environment have been found to be fairly constant throughout the world at 0.03% and 20.00%, respectively. Nature maintains this balance by the continual process of the carbon cycle, wherein carbon dioxide used during photosynthesis is restored to the environment by processes such as respiration, decay, and burning.

Carbon from carbon dioxide is first of all incorporated into carbohydrates such as sugar and starch and eventually into other organic compounds such as proteins and fats, which comprise living organisms. When the plants are eaten by animals, these organic compounds in the plants are built up into other organic compounds such as carbohydrates, proteins, and fats, which also make up the animal tissues. Thus, carbon from the plants becomes a part of the animals.

Plants and animals obtain energy by the oxidation of carbohydrates present in their cells to carbon dioxide and water. These products are excreted and carbon dioxide is added to the environment.

Besides oxidation of carbohydrates during respiration, other ways by which carbon dioxide is added to the environment are as follows:

(a) After the death of animals and plants, their organic matter is used by microorganisms as a source of food and energy. Microorganisms decay and decompose the animal and plant remains and convert the carbon compounds into carbon dioxide.

(b) During accidental forest fires and deliberate burning of fuels such as coal, petroleum products, and natural gas, carbon is oxidised to carbon dioxide. (Prehistoric forests which have only partly decomposed over the millions of years since they were buried give rise to these fuels.)

SECTION 6: GROWTH AND GROWTH MOVEMENTS (TROPISM)

Growth is an essential characteristic of all living

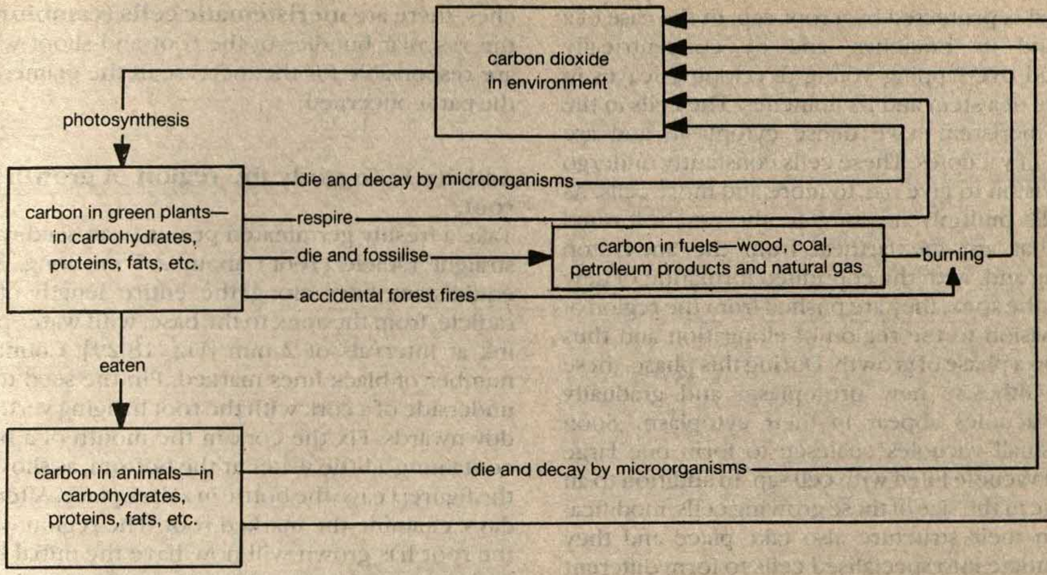

carbon dioxide in environment
photosynthesis
carbon in green plants—in carbohydrates, proteins, fats, etc.
die and decay by microorganisms
respire
die and fossilise
carbon in fuels—wood, coal, petroleum products and natural gas
burning
accidental forest fires
eaten
carbon in animals—in carbohydrates, proteins, fats, etc.
die and decay by microorganisms

FIG. 18.26 Carbon cycle

organisms. Growth is defined as an irreversible and permanent increase in the size of an organism or its parts as a result of metabolism, and is accompanied by an increase in weight and complexity and a change in form during the course of development. When **anabolism** (constructive or building up metabolism) exceeds **catabolism** (destructive or breaking-down metabolism), new protoplasm is formed in living cells with the help of nutrients absorbed by them. Also, some cells produce protoplasm themselves. New protoplasm helps the cells in increasing their size.

A plant grows throughout its life span, provided environmental conditions are favourable and nutrients are available. In lower plants such as bacteria, fungi, and algae, the entire plant body is capable of growh, but, in higher plants, such as ferns and flowering plants, growth is restricted mainly to the growing regions situated near the apex of their roots, stem, and their branches. This type of growth is known as **apical growth**.

The growing apex of a root or shoot consists of three regions:

(a) the region of cell division or dividing cells;
(b) the region of cell elongation or growing cells; and
(c) the region of maturation or grown-up cells.

At the extreme apex of every root and stem and their branches is the **apical meristem**. This deli-

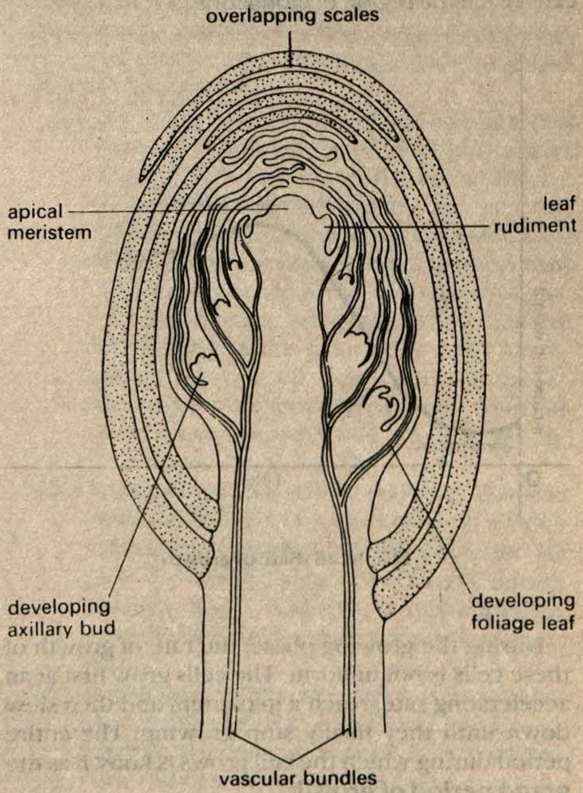


FIG. 18.27 Longitudinal section through tip of growing stem

cate part is protected by a root cap, in the case of a root and its branches, and by concentrically arranged overlapping young developing leaves in the case of a stem and its branches. The cells in the apical meristem have dense cytoplasm and are devoid of vacuoles. These cells constantly undergo cell division to give rise to more and more cells. As the cells multiply in number, the newly formed ones that are the farthest from the apex stop dividing and, with the continued formation of new cells at the apex, they are pushed from the region of cell division to the region of elongation and thus enter on a phase of growth. During this phase, these cells synthesise new protoplasm and gradually small vacuoles appear in their cytoplasm. Soon these small vacuoles coalesce to form one large central vacuole filled with cell sap. In addition to an increase in the size of these growing cells, modifications in their structure also take place and they differentiate into specialised cells to form different tissues such as epidermis, parenchyma, and collenchyma. These cells are pushed back further into the region of maturation as more newly formed cells reach the region of elongation.

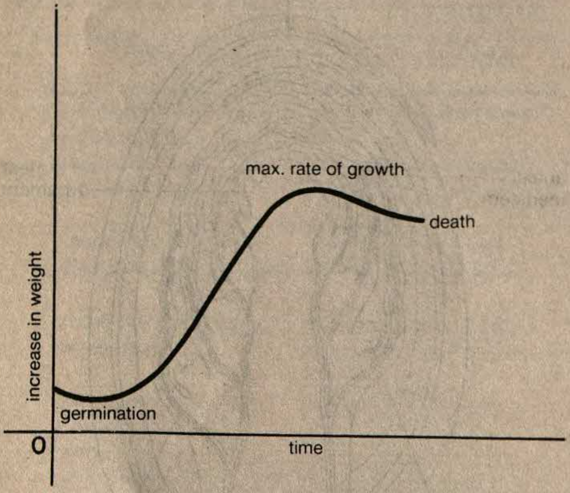


FIG. 18.28 **Rate of growth**

During the growing phase, the rate of growth of these cells is not uniform. The cells grow first at an accelerating rate, reach a maximum and then slow down until they finally stop growing. The entire period during which the cell grows is known as the **grand period of growth.**

Whereas the activity of the apical meristem leads to elongation of the root, the shoot, or their branches, there are **meristematic cells (cambium)** in the vascular bundles of the root and shoot which are responsible for the increase in the diameter of the part concerned.

Activity 1: To study the region of growth in a root.

Take a freshly germinated pea or bean seed with a straight radicle (root) about 2.5 cm long. Mark equidistant lines along the entire length of the radicle, from the apex to the base, with water-proof ink at intervals of 2 mm [Fig. 18.29]. Count the number of black lines marked. Pin the seed to the underside of a cork with the root hanging vertically downwards. Fix the cork in the mouth of a bottle containing a little water at the bottom, as shown in the figure. Leave the bottle in a dark place. After two days, examine the marked root. The region where the root has grown will now have the initial black lines separated by more than 2 mm. Numbering the black line closest to the tip of the root as 1, the next higher one as 2, and so on, measure the new length of the root between lines 1 and 2, 2 and 3, and so on. Formulate a table showing the initial separation and the new separation between each pair of consecutive black lines. From this table, deduce the regions of maximum growth and those of 'no growth' of the root. Which region, relative to the position of the tip of the root, shows the maximum growth? Above which black line does the root show no growth' at all?

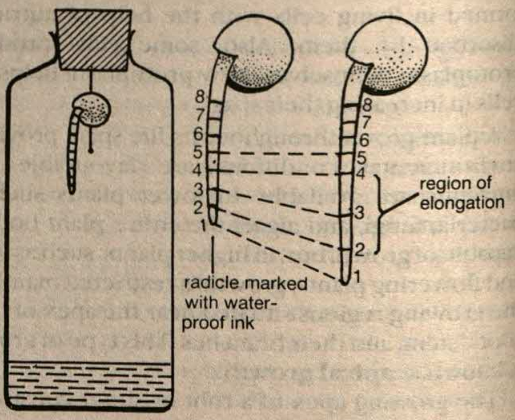


FIG. 18.29 **Experimental setup to study region of growth in root**

Activity 2: To study the region of growth in a shoot.

To perform this experiment, repeat the above procedure with a young pea or bean seedling supported vertically in a bottle containing water. As done earlier, mark equidistant lines along the entire length of the growing shoot, from the apex to the base, with water-proof ink at intervals of 2 mm. Leave the seedling aside for two days, and then measure the new distances of separation between the marked lines. Tabulate your observations as in the previous activity. Determine which parts of the shoot show (1) maximum growth, (2) moderate growth, and (3) 'no growth'. Are the regions of growth extended to the same lengths in the root as well as in the shoot?

MEASUREMENT OF GROWTH

Even at its maximum rate of growth, a plant grows rather slowly. Nevertheless, the rate of growth can be measured with the help of a simple instrument known as the **arc** or **lever auxanometer**. This instrument magnifies even a small increase in the size of a growing part of a plant, and from the magnified growth recorded by the auxanometer, the actual length gained by the growing part within a specified period can be easily calculated.

The auxanometer consists of a movable lever indicator, fixed to a wheel or pulley, and a graduated arc fixed to a stand [Fig. 18.30]. A string is passed round the wheel: one end of the string is tied to the growing tip of a shoot (whose rate of growth is to be measured), and, to the other end of the string, a small weight is attached to keep the string taut. An increase in the length of the shoot causes the wheel to rotate gradually, and this movement causes the lever indicator to move down the graduated arc. The growth during a specified period is thus recorded by the shift in the position of the lever indicator on the arc on a magnified scale. Knowing the magnification of this scale, the actual increase in length and thus the rate of growth can be easily calculated. For example, if the lever indicator has moved a distance of 50 cm on the arc in 24 hours and the magnification is 100 times, the actual growth in the same period is 50/100 cm, or 0.5 cm, and, therefore, in one hour the actual growth of the plant is 0.5/24 or 0.02 mm.

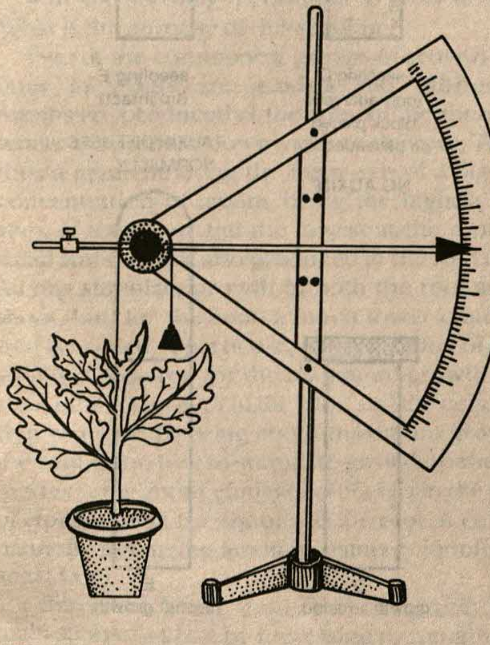


FIG. 18.30 Experimental setup with auxanometer

CONDITIONS NECESSARY FOR GROWTH

Growth in a living organism occurs as a result of the activities of its protoplasm. Consequently, growth occurs under conditions which help the activities of the protoplasm. The following are the essential conditions for growth:

(i) A constant supply of nutritive substances is essential for building up new protoplasm and for cell respiration. These substances include carbohydrates, fats, and proteins which are manufactured by the plant itself and a variety of mineral salts absorbed from the external soil. These mineral salts provide the elements essential for the healthy functioning of the plant body and a shortage of any one of these elements causes unhealthy deficiency symptoms. Some of these elements are N, Mg, Ca, P, S, Fe, Zn, Cu, Mo, Mn, Be, K, and Cl.

(ii) Water should be readily available. Water is essential for the transportation of various substances required by the plant for its growth, besides being a raw material during photosynthesis. It maintains the turgidity of the cells which is essential for cell enlargement.

(iii) A constant supply of oxygen is indispensable for the cellular respiration in order to provide the energy required for metabolism which leads to growth.

(iv) An optimum temperature of 25–30°C is considered ideal for the functioning of enzymes which control all cellular activities. At lower temperatures, the enzyme action is slowed down and the growth is retarded. At higher temperatures, the enzymes are destroyed and the plant dies. However, some plants grow well even at temperatures lower than 20°C and higher than 30°C.

(v) Besides being a source of the energy required for photosynthesis, sunlight with an optimum intensity and duration is essential for the healthy growth of plants. Sunlight facilitates the exchange of gases and is essential for the growth of the reproductive parts in a plant and also for the formation of chlorophyll. Plants growing in the continued absence of sunlight develop soft stems with long internodes and small yellowish leaves. This condition is known as **etiolation**. A plant ultimately dies due to prolonged etiolation.

(vi) Certain organic chemical substances, called **growth hormones** (produced by the plant itself), have a significant effect on the growth of the plant. These hormones act in very low concentrations. They are produced in some cells during metabolism and, being soluble in water, they diffuse easily from cell to cell to influence the activities of some other specific tissues.

Activity 3: To show that some chemical substances stimulate growth.

Germinate some maize grains in darkness and allow the seedlings to grow for a few days till the **coleoptiles** (shoots) are about 20 mm long. Select five healthy seedlings having about 20-mm-long coleoptiles. Label them as A, B, C, D, and E.

Cut off 2 mm tips from the growing coleoptiles of seedlings A, B, C, and D. Throw away the tip of seedling A. Replace the tip of seedling B on the be-

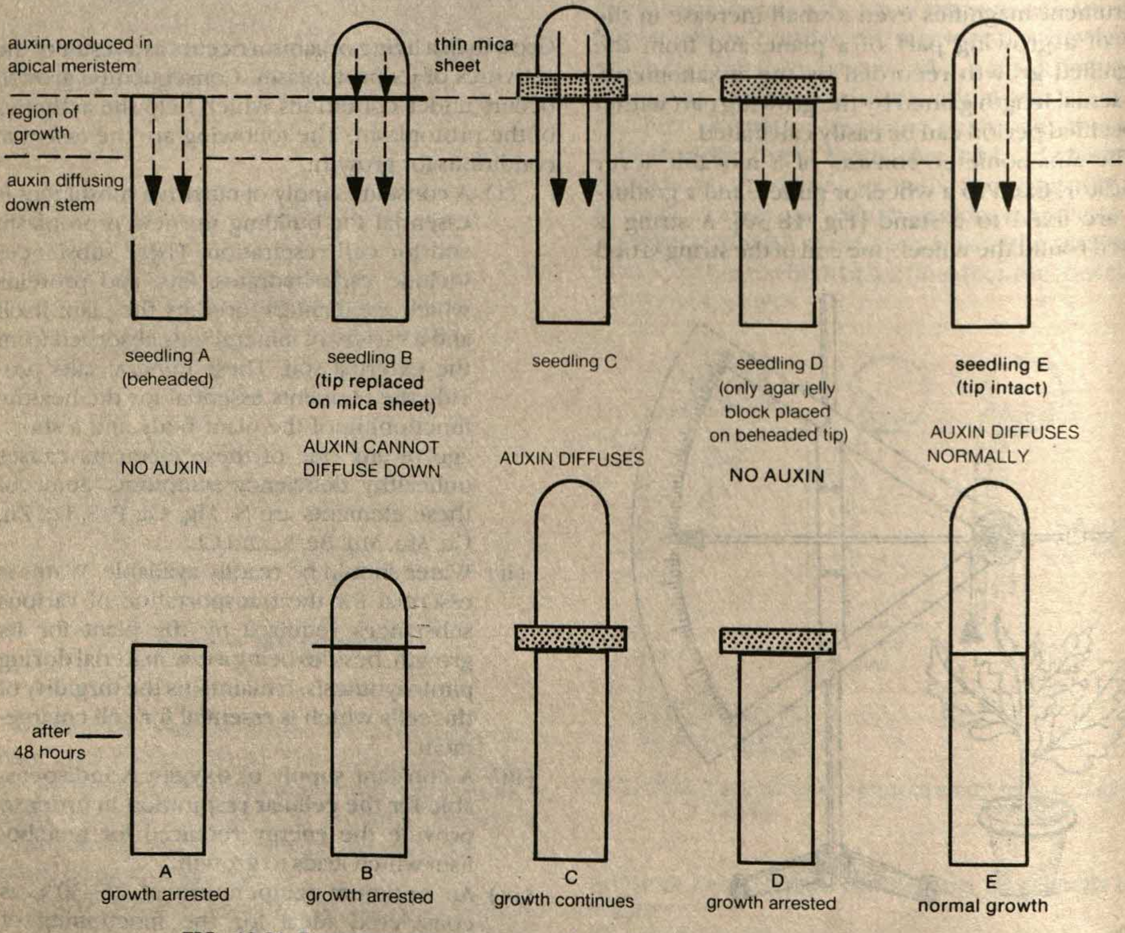


FIG. 18.31 Experimental setup to show that auxins stimulate growth

headed shoot but separated from it by a thin sheet of mica. Replace the tip of seedling C on the beheaded shoot but separated from it by a small block of agar jelly. Throw away the tip of seedling D, but place a small biock of agar jelly on this beheaded seedling. Leave seedling E as it is without cutting its tip.

Allow all five seedlings to grow in similar conditions of light and temperature. After about 48 hours, compare the growth of seedlings A, B, C, and D with that of E. It will be observed that while the growth of seedlings A, B, and D is arrested, seedlings C and E continue to grow normally. The reasons are as follows: Coleoptile tips with the apical meristems produce growth-promoting chemical substances which

(a) failed to reach the region of growth (elongation) in seedling A since its tip was cut off and thrown away,
(b) failed to reach the region of elongation in seedling B since mica prevented their diffusion,
(c) reached the region of elongation in seedling C in spite of the block of agar jelly which allowed their diffusion from the tip to the region of elongation, and
(d) did not reach the region of elongation in seedling D since its tip was cut off and thrown away, and only a block of agar jelly was placed on the beheaded seedling.

Why did seedling E continue to grow normally? What is the purpose of this seedling?

Two of the commonest groups of growth hormones in plants are **auxins** and **gibberalins**. Auxins are produced at the apex of the shoot from where they diffuse downwards to the root. There is thus a gradient along the main axis of a plant, the concentration of auxins being the highest at the apex of the shoot and the lowest at the root. Very small amounts are also produced in the root apices. Auxins stimulate growth in both the root and the shoot, but, for the root, a much lower concentration is needed. A particular concentration of auxins which is required for the maximum growth in the stem inhibits growth in the root, and the concentration required to bring about maximum growth in the root is too low to stimulate growth in the stem. Auxins bring about elongation of cells in the region of elongation in the shoot and the root. A common naturally occurring auxin in plants is indoleacetic acid (IAA).

Gibberalins bring about the elongation of the main stem of a plant by increasing the length of the internodal region. They tend to inhibit the growth of the main root. Like auxins, gibberalins exert their growth-promoting influence mainly by causing cell elongation.

THE RESPONSE OF PLANTS TO EXTERNAL STIMULI

When a seed is planted in soil, under suitable conditions, it germinates within a few days. In whatever position the seed may have been placed, the root always emerges with a downward growth into the soil, whereas the shoot always emerges with an upward growth into the atmosphere above the surface of the soil. This sense of direction which a germinating seed or a seedling shows is the **response** of the plant to external stimuli. In this case, the root responds to the stimulus of gravity, soil water, and soil air, whereas the shoot responds to that of atmospheric air and light.

The ability to respond to stimuli (or irritability or sensitivity) is characteristic of all living organisms—animals as well as plants. Whereas the animals respond quickly to stimuli and their responses can be easily noticed, the responses in plants are rather slow and cannot be readily observed.

Plants respond to a variety of stimuli such as light, gravity, temperature, water, chemical substances, and contact. In some plants, the leaves are held outspread during the daytime, but at night they collapse and droop down. Many flowers close up at night, while there are some which bloom only at night. Thus, plants and flowers respond to the stimuli of light, darkness, and variation of temperature. Such responses which are due to diffuse stimuli that do not come from any particular direction are called **nastic responses**. Responses of plants to stimuli which are directional and, as a consequence of which, the plant organs either grow towards the direction of the stimulus or away from it are known as **tropic responses** or **tropisms**. In other words, the direction of response is related to the direction of stimulus.

We shall now describe the more important tropisms exhibited by plants:

(i) **Phototropism** is the response of the parts of a plant to the directional stimulus of light. Usually, stems grow towards light and are said to be **positively phototropic**. Roots usually grow away from light and are said to be **negatively phototropic**. How do the stems of indoor plants kept on a window sill or kept close to a window respond to the directional stimulus of light? Positive phototropism exhibited by the stems is an adaptation of the plants by which their leaves are exposed to sunlight for photosynthesis.

(ii) **Geotropism** is the response of a part of a plant to the directional stimulus of gravity. The primary root grows vertically downwards in the soil in response to the gravitational pull of the earth, and is said to be **positively geotropic**. On the contrary, the main stem of a plant grows vertically upward, in a direction opposite to that of the force of gravity, and is said to be **negatively geotropic**.

(iii) **Haptotropism** or **thigmotropism** is the response of a part of a plant to the directional stimulus of physical contact with a body in the external world. All plants possessing tendrils (e.g., pea, grape, cucumber) show haptotropism since their tendrils, on coming into contact with any hard object, coil around it for support. Such plants use the property of haptotropism to climb and grow.

(iv) **Hydrotropism** is the growth movement of a plant organ in response to the directional stimulus of moisture. Roots grow towards a source of moisture and are said to be **positively hydrotropic.** The roots of plants growing in a hanging basket (made of wire netting and filled with moist soil) hang out of the basket at first because of positive geotropism. But after some time, the roots grow upwards, forming loops, to enter the moist soil again. This happens because the roots grow in the direction of the moisture.

Activity 4: To show the effect of directional illumination (light) on the growth of main stems.

Take a box containing three compartments, A, B, and C, as shown in the figure [Fig. 18.32]. Each compartment is fitted with a shutter on one side. Compartment A has a wooden shutter and so does compartment B. But the latter shutter has a small opening in it which allows light to enter the compartment from one side. Compartment C has two glass shutters and a glass top, so that light can enter from all three sides.

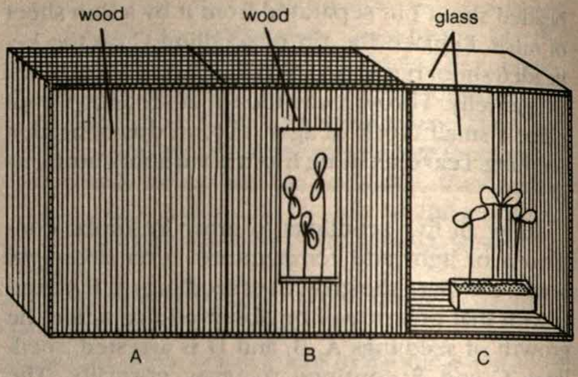


FIG. 18.32 Experimental setup to demonstrate the effect of light on growth of main stems

Take all the shutters out of the box and place a small container carrying moist soil and some soaked seeds in each compartment. Replace the shutters and keep the box in open air for a week or so. The seeds will germinate during this period. The seedlings in compartment A grow in complete darkness, those in compartment B grow with light incident on them from only one side, whereas those in compartment C grow with light incident on them from all sides.

At the end of one week, it will be observed that the seedlings in compartment A have long, weak, straggling stems, and sickly, yellow, underdeveloped leaves. Next, the seedlings in compartment B have stems growing towards the hole in the shutter through which light enters the compartment. The leaves of these seedlings also will be facing the light so that the incident rays are perpendicular to their laminas. These seedlings will be moderately healthy. Finally, the seedlings in compartment C will have vertical, erect stems with well-developed green leaves. From these observations, what conclusions can you draw about the influence of light on the growth of stems? Which observation enables you to conclude that a stem is positively phototropic? Which observation demonstrates etiolation?

Activity 5: To show that the tips of shoots are sensitive to light.

Germinate some barley grains in a pot of damp soil kept in a dark cupboard. When the shoots (coleoptiles) have grown to about 2 cm in height above the soil, cover the tips of some with caps of tin foil. Cut off the tips of a few more and leave the remainder untouched. Keep this pot with the seedlings inside

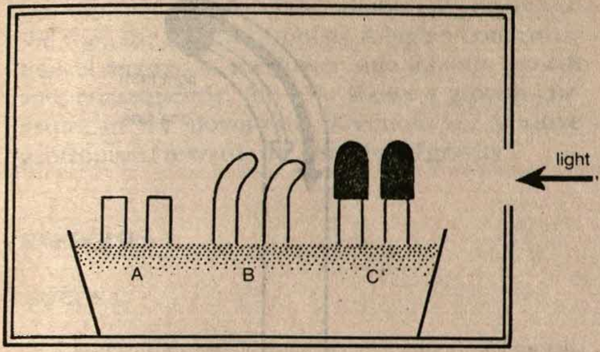


FIG. 18.33 Experimental setup to show that tips of shoots are sensitive to light

a closed box with a hole on one side to admit light from that side only. Leave the box near a well-lit window with the hole facing the light. After a day or so, examine the seedlings in the pot. Do they all grow to the same height? Do some shoots only or do all shoots show definite phototropism? Why do only some shoots show phototropism? What is the effect of tin foil caps on the growth? What conclusions do you draw from these observations?

Activity 6: To show the effect of gravity on shoots.

Select two pots, A and B, with identical healthy seedlings growing in them. Place pot A on its side so that the stem is horizontal to the ground. Place pot B horizontally on a **clinostat**. (A **clinostat** is a device that has a turntable driven by an electric motor and rotates about its central axis [Fig. 18.34].) Adjust the speed of the clinostat so that the turntable undergoes four rotations per hour. The seedling in pot B will now be exposed to the force of gravity equally on all sides. Place both the potted plants in a dark chamber and leave them to continue their growth. Take them out after 24 hours, and observe their condition.

Although both pots are placed on their sides and are exposed to the stimulus of gravity alone, why does the seedling in pot A bend and begin to grow vertically while that in pot B continues to grow straight horizontally? What conclusion can you draw from these two observations? State your reasoning clearly. What shape will the shoot assume if the speed of rotation is very slow? Give reasons. What will be the response of the shoot if the speed of rotation is extremely fast? Give reasons. What is the exact function of the clinostat?

Activity 7: To show the effect of gravity on primary roots.

Pin a few seedlings with straight radicles to a large cork as shown in the figure [Fig. 18.35]. Place the cork in the mouth of a jar and leave it on its side (horizontal) on the ground for 48 hours. Set up a similar jar and place it on a clinostat as a control apparatus. The insides of both containers have to be lined with moist blotting paper and both jars should be placed in a dark room. What do you observe after 48 hours? Why do the radicles in the first jar bend and begin to grow vertically downwards again, while those in the control jar continue to grow horizontally? The moist blotting paper is used to saturate the air inside each jar with water vapour.

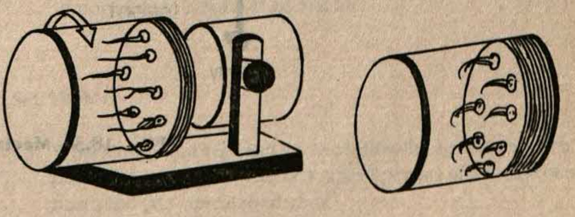


FIG. 18.35 Experimental setup to demonstrate effect of gravity on primary roots

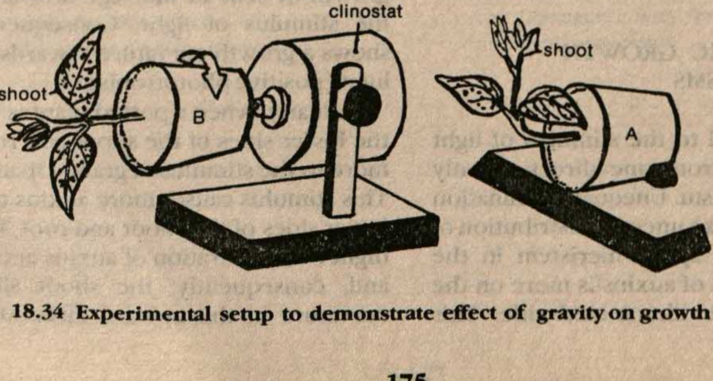


FIG. 18.34 Experimental setup to demonstrate effect of gravity on growth of main stems

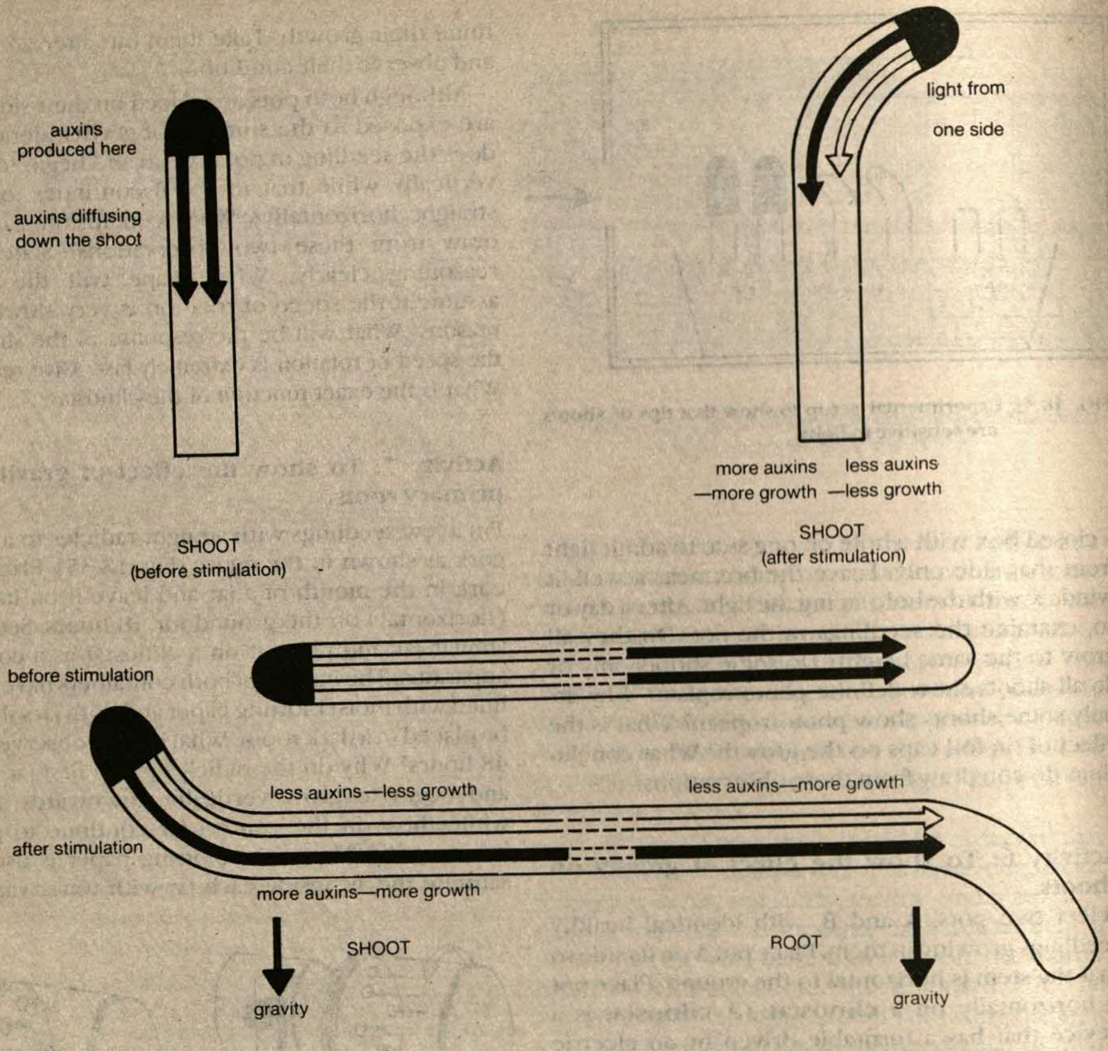


FIG. 18.36 Mechanism of tropisms

Why is this saturation necessary? What would happen if both jars were left in sunlight instead of darkness?

MECHANISM OF TROPIC GROWTH MOVEMENTS OR TROPISMS

Shoots of plants exposed to the stimulus of light acting (on the plants) from one direction only show positive phototropism. Unequal illumination of the shoot brings about an unequal distribution of auxins produced in the apical meristem in the shoot. The concentration of auxins is more on the darker side than on the illuminated side. This results in a relatively faster growth of cells in the region of elongation on the darker side and slower growth of cells in the region of elongation facing the stimulus of light. Consequently, the shoot shows a growth curvature towards the stimulus of light (positive phototropism).

Similarly, when a potted plant is kept horizontal, the lower sides of the shoot and root are exposed more to the stimulus of gravity than the upper side. This stimulus causes more auxins to collect on the lower sides of the shoot and root. In the shoot, the higher concentration of auxins accelerates growth and, consequently, the shoot shows a growth curvature in the upward direction, i.e., negative geotropism (away from the stimulus of gravity). In the root, the reverse happens. A higher concentration of auxins on the lower side inhibits growth and, consequently, the root shows a growth curvature in the downward direction, i.e., positive geotropism (towards the stimulus of gravity).

EXERCISES

SECTION 1

1. Clearly distinguish diffusion, active transport, and osmosis from each other.
2. (a) Describe the structure of a root hair with the aid of a simple diagram.
   (b) What are the functions of root hairs and how are they carried out?
3. How are water and mineral salts absorbed into the root system of a plant? Clearly describe the processes involved.
4. What do you understand by 'flaccid' and 'turgid' conditions of a cell? How do the flaccidity and turgidity of root cells help in the absorption of water and mineral salts?
5. What is root pressure, and in what manner is it vital to the life of a plant?

SECTION 2

6 (a) What is transpiration?
   (b) How is transpiration vital to the life of a plant?
7. (a) Describe the function of stomata in transpiration.
   (b) What is the function of the cuticle in transpiration?
8. (a) How does the suction of cell sap occur in the process of transpiration?
   (b) What is the importance of suction due to transpiration in the life of a plant?
9. List the conditions which affect transpiration, and state how each affects the rate of transpiration.
10. How will you demonstrate that:
   (a) Water vapour is given off during transpiration?
   (b) Transpiration occurs at different rates from the two sides of a dorsiventral leaf?

SECTION 3

11. Describe the path taken through a plant by a molecule of water from the soil to the atmosphere.
12. What factors enable the ascent of sap in a plant?

SECTION 4

13. Describe, with the aid of a simple equation, the basic chemical reaction involved in photosynthesis.
14. Where in a plant does photosynthesis mostly take place? List all the essential requirements for this process.
15. Describe the roles played by the following in the process of photosynthesis: (i) mesophyll cells; (ii) chlorophyll; (iii) photolysis; and (iv) ATP.
16. State the importance of photosynthesis in the life of the following: (a) green plants; (b) non-green plants; and (c) animals.
17. Trace the path followed by (i) a molecule of oxygen from the atmosphere to the pith of a stem and (ii) a molecule of carbon dioxide from the atmosphere to the place where it is required for photosynthesis.
18. Excess water within a plant first collects as a thin film on the outside of the mesophyll cells of a leaf. Why is this film of water essential for the life of a plant?

SECTION 5

19. What is the difference between internal and external respiration? Explain with reference to man.
20. Why, where, and when does respiration take place in green plants?
21. How do plants respire? Explain the roles of stomata, guard cells, and lenticels in this process.
22. Distinguish clearly between aerobic and anaerobic respiration.
23. Tabulate similarities and differences between photosynthesis and respiration in plants.
24. Briefly outline the carbon cycle in nature and explain its importance in plant and animal life.

SECTION 6

25. What do you understand by the following terms: (a) Tropism; (b) apical growth; (c) grand period of growth of a plant; and (d) apical meristem?
26. List all the essential conditions required for the growth of a plant and state how they help the growth.
27. (a) Name five environmental stimuli and the corresponding tropic movements of a responding plant.
   (b) Distinguish, with three examples, between positive and negative tropisms.

Part 5: The Biology of Animals

CHAPTER 19

Nutrition in Animals

SECTION 1: THE IMPORTANCE OF FOOD

The prime concern of all animals, including man, is how to obtain food, which is absolutely essential to keep them alive. Food, in sufficient quantities, and of the right and suitable kind, is the foremost requirement for developing and maintaining a healthy body. Food is, in fact, the 'fuel' that keeps the various organs of the body functioning. Food is required for several purposes; the important ones are as follows:

To provide energy: Energy is required for all activities of the body and is obtained by the chemical breakdown or oxidation of food substances in living cells during respiration.

For the growth of the body: All living cells are made up of protoplasm, which is in a perpetual state of change. In protoplasm, some chemical compounds are constantly being broken down and others constantly being formed. Food is required as the raw material from which new compounds are built up to form new protoplasm. When the protoplasm is built up faster than it is broken down, the living body grows.

For the maintenance and repair of old tissues in the body: Because of the constant chemical activities taking place in the living body, the tissues are subjected to a lot of wear and tear. Food is required to provide the materials necessary to repair, renew, or replace the protoplasm in worn-out cells and tissues.

To provide protection against disease and ill-health: For regulating and maintaining the health of the body and for protecting it against various diseases, substances such as vitamins and mineral salts are required, which are obtained through food.

SECTION 2: CLASSES OF FOOD

All food substances are, in fact, chemical compounds which may be classified into various groups: carbohydrates; proteins; fats and oils; vitamins; mineral salts; and water.

CARBOHYDRATES

Carbohydrates are organic compounds of carbon, hydrogen, and oxygen, in which hydrogen and oxygen are in the same proportion as in a molecule of water (H_2O). Carbohydrates are available from edibles such as wheat, rice, maize and all other cereals, potatoes, milk, fruits, jam, honey, and cakes. All carbohydrates are formed in plants during photosynthesis.

The carbohydrates present in food are of three types:

(i) **Monosaccharides:** These are simple sugars, e.g., glucose, fructose, and have the formula $C_6H_{12}O_6$. These sugars are sweet to taste and are soluble in water.

(ii) **Disaccharides:** These are complex sugars, e.g., sucrose (cane sugar), maltose (malt sugar), and lactose (milk sugar), and are formed by the condensation of two molecules of a monosaccharide. Their formula is $C_{12}H_{22}O_{11}$. These sugars, too, are sweet and are often soluble in water.

(iii) **Polysaccharides**: These are composed of many sugar molecules, e.g., starch, glycogen, and cellulose. Their formula is $(C_6H_{10}0_5)_n$. These sugars are not sweet and are insoluble in cold water.

During the process of digestion, larger molecules of complex carbohydrates such as starch are changed (hydrolysed) to simple molecules such as sugars by the action of enzymes called **amylases** or **amylolytic enzymes**.

Carbohydrates are the energy-giving or 'fuel' foods, and each gram of carbohydrate releases 17 kJ (17,000 joule) of heat energy on oxidation. Excess carbohydrates are built up into glycogen (animal starch) for storage in the liver and muscle cells. If present in considerable excess, carbohydrates are converted into fats.

Activity 1: To determine the presence of carbohydrates in food.

(i) **Test for glucose (reducing sugar)**: Boil 5 ml of a 5% glucose solution with either (a) 5 ml of a mixture of equal quantities of **Fehling's A and B solutions**, or (b) 5 ml of **Benedict's solution**. In either case, you will obtain a deep blue mixture, which, on boiling, first turns light green, then dirty green, and finally brick red. This final red colour is due to cuprous oxide precipitated by the reducing action of sugar on the copper sulphate contained in the reagents.

If a food material is dissolved in water and tested with these two reagents in the above manner and a brick red precipitate is obtained, it may be concluded that the food substance contains the soluble carbohydrate glucose.

(ii) **Test for sucrose (non-reducing sugar)**: A non-reducing sugar, such as sucrose (cane sugar) will not ordinarily react with either Fehling's solution or Benedict's reagent as in the previous case, but will do so if a sample of sucrose is first boiled with a few drops of dilute hydrochloric acid and then made alkaline with an excess of sodium hydroxide. The hydrochloric acid breaks down or **hydrolyses** the sucrose into two simple sugars, as shown:

$$\text{sucrose} \xrightarrow[\text{by acid}]{\text{broken down}} \text{glucose and fructose}$$

The alkaline solution is then tested for a reducing sugar with either Benedict's reagent or Fehling's solution. Such a test gives the same results as in the previous case, thus indicating the presence of glucose or a reducing sugar in this solution. Thus, if a food substance, when hydrolysed, reacts with either Fehling's solution or Benedict's solution to give a brick red colour, that substance contains sucrose or non-reducing sugar.

(iii) **Test for starch**: Add a few drops of dilute **iodine** solution to a food rich in starch, e.g., a slice of potato. A blue-black colouration is obtained, which indicates the presence of starch.

PROTEINS

Proteins are highly complex organic compounds, made up of hundreds of amino acid molecules which contain the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus. These amino acid molecules are joined together by **peptide bonds**.

Proteins are insoluble because their molecules are large and complex. During the process of digestion, proteins are converted to simple and soluble amino acids by enzymes called **proteases** or **proteolytic enzymes**.

Common foods which are rich in protein include lean meat, egg white, milk, cheese, leguminous seed (all beans and pulses), fish, and groundnuts.

Proteins are used for building up fresh protoplasm and new cells, which are required for the growth and repair of body tissues. Hence, growing children require foods that are especially rich in protein. Proteins release energy when oxidised—one gram of protein yields 17 kJ (17,000 joule) of heat energy during its oxidation.

Proteins cannot be stored in the body, and if taken in excess, they are either converted to glycogen, which is stored in the body, or to urea which is excreted from the body by the kidneys.

Activity 2: To test a food substance for the presence of proteins.

(i) **Xanthoproteic test**: Add a few drops of concentrated nitric acid to a solution of egg albumen. A white precipitate is formed. Boil the mixture; the white precipitate turns yellow. Cool the mixture and add a few drops of concentrated ammonia solution; the yellow precipitate turns orange in colour.

(ii) **Millon's test**: Mix a solution of egg albumen with an equal quantity of Millon's reagent. A white precipitate is formed which becomes dirty red in colour when the mixture is boiled.

(iii) **Biuret test**: Add 1% sodium hydroxide solution to a solution of food rich in protein and one drop of 5% copper sulphate solution. A purple colouration is observed.

FATS AND OILS

Like carbohydrates, fats and oils contain carbon, oxygen, and hydrogen. In a fat molecule, however, the atoms of hydrogen and oxygen are not present in the same ratio as in a water molecule. Although chemically alike, fats and oils can be distinguished from each other simply by the fact that at normal room temperature fats are in a solid state and oils in a liquid state. Common sources of oils and fats include vegetable oils like coconut oil, palm oil, mustard oil, and groundnut oil, fat meat, butter, nuts, ghee and egg yolk.

During the process of digestion, fats and oils are converted to fatty acids and glycerol by **enzymes** called **lipases** or **lipolytic enzymes**. Fats and oils are complex and insoluble, whereas fatty acids and glycerol are simple and soluble. Fats and oils are the best energy-giving foods and each gram of fat or oil releases 38 kJ of heat energy on oxidation, i.e., more than twice the energy given out by the same quantity of carbohydrates or proteins. However, the main function of fats is storage. Like carbohydrates, fats can be stored for use when the occasion arises. Excess fats and oils are stored in the body, generally as subcutaneous fat under the skin.

Activity 3: To test a food substance for the presence of fats and oils.

(i) A simple test to determine the presence of fats is to rub a food substance rich in fats on a piece of paper. The rubbing leaves a permanent greasy mark on the paper, which thus becomes translucent. A similar result is obtained when a few drops of oil are placed on paper.

(ii) Add a few drops of alcoholic solution of the red dye **Sudan III** to a suspension of oil drops in water in a test tube. The Sudan III soon stains the oil drops red, and the water remains colourless.

VITAMINS

Vitamins are organic compounds which are absolutely essential for the normal working of the body. They are required in very small quantities, but if our diet is lacking in one or more vitamins, we suffer from certain diseases called **deficiency diseases**. These diseases can be cured by including the necessary vitamins in the diet. The vitamins available in the form of capsules or tablets at a chemist's store are synthetic (not natural). Our bodies can also synthesise certain vitamins, like A and D, under certain conditions. Vitamins need not be digested and they cannot be stored by the body, except for vitamin A and riboflavine. They are easily destroyed due to bad storage and the faulty cooking of foods. For example, vitamin C is easily destroyed by heat. Vitamins B and C are soluble in water, whereas others, A, D, E, K, etc., are soluble in fats.

When deficiency diseases were first recognised and studied, the chemical structure of vitamins was not known. Consequently, the vitamins were simply denoted by A, B, C, D, and so on. Most of the vitamins are now chemically very well known and many can be synthesised even in the laboratory.

Some of the better known vitamins are discussed in Table 19.1.

MINERAL SALTS

Mineral salts provide the chemical elements required for the normal functioning of the body and for the formation of certain tissues. Normally, our food contains these minerals salts in small quantities, sufficient to meet the normal requirement of the body.

Iron salts are necessary for chlorophyll synthesis in green plants and for the formation of **haemoglobin**, which is essential for the red blood cells in the activity of transporting oxygen. Deficiency of iron causes **anaemia**. Sea foods, egg yolk, green leafy vegetables, whole grain cereals, nuts, peas, beans, etc., are rich in iron.

Calcium and **phosphorus** salts are essential for the proper formation of **bones** and **teeth**. Calcium also plays an important part in the **clotting of blood**, while phosphorus also helps release energy from food. Milk, cheese, egg yolk, pulses, grams, groundnuts, soyabeans, liver, kidney, fish, etc., are rich in calcium and phosphorus.

Sodium salts are essential for (1) blood plasma, (2) proper kidney functioning, and (3) the smooth transmission of nerve impulses. We acquire sodium mainly as sodium chloride (common salt).

Iodine is extremely important for the proper functioning of the **thyroid gland**, whose secretion, called thyroxine, controls the general development of the body. The deficiency of iodine causes **simple**

TABLE 19.1 VITAMINS AND THEIR CHARACTERISTICS

VITAMIN	PRINCIPAL SOURCES	EFFECTS OF DEFICIENCY
A (Retinol)	Spinach, tomatoes, carrots, liver, animal fats, fish liver oils, palm oil, buttermilk, egg yolk.	Poor night vision; retarded growth, loss of weight. Poor resistance to infections of skin, and of respiratory and digestive systems. Skin and cornea of eyes become dry, causing **xerophthalmia.**
B_1 (Thiamine)	Yeast, unpolished rice, eggs, fruits, cheese, milk, liver, kidney.	Loss of appetite and weight, swelling of legs and feet, causing **beri-beri.**
B_2 (Riboflavine)	Green leafy vegetables, yeast, fruits, liver, egg white, milk, fish.	Slow growth in children, sore cracks on the lips and tongue, itching and burning eyes, causing **conjunctivitis.**
B_5 (Nicotinic acid/ niacin)	Cereals, fish, liver, meat.	**Pellagra,** a disease characterised by sore mouth and tongue, depression, disturbed digestive system.
B_{12} (Cobalamine)	Meat, liver, milk.	**Pernicious anaemia** (lack of red blood cell production.)
C (Ascorbic acid)	Orange, lemon, tomato, guava, mango, green leafy vegetables, cabbage, melons.	**Scurvy**, a disease characterised by weakness, loss of weight, haemorrhages of the skin, especially in the mouth and gums, poor healing of wounds, anaemia.
D (Calciferol)	Liver, milk, egg yolk, fish liver oils, animal fats, butter. (From the natural fats stored under the skin, our body can manufacture this vitamin with the help of sunlight.)	**Rickets,** a disease affecting children, in which bones fail to harden and become deformed. Poor teeth, poor absorption of calcium and phosphorus.
E (Tocopherol)	Green vegetables, wheat germ, egg, olive oil.	**Sterility**, in male and female rats. (Not confirmed in human beings.)
K (Phulloquinone)	Green vegetables, especially spinach, cabbage, and liver.	Blood clotting is very slow, proneness to haemorrhage.

goitre. We get the required quantity of iodine from drinking water. Iodised salt and sea foods also are rich in iodine.

WATER

Water forms about 70% of our body weight. It is an essential part of the living protoplasm and of the body fluids such as blood, lymph, and digestive juices. Water forms the bulk of blood plasma, which is responsible for transporting food substances and waste products from one part of the body to another. In the absence of water, vital chemical reactions in the living cells slow down and finally stop. Also, digestion of food cannot take place without water.

A BALANCED DIET

To maintain a healthy body, it is absolutely essential to include the required quantities of all the six classes of food in our daily diet, i.e., carbohydrates and fats to provide energy, proteins for growth and for the replacement of worn-out tissues, mineral salts and vitamins as protective foods, and water to replace that which is lost during respiration, digestion, excretion, etc. Since we cannot obtain all these substances from just one or even a few food substances, we must include a wide variety of foods in the appropriate proportions in our daily diet. **A balanced diet** is one which provides sufficient quantities of **good quality** calorific foods containing **correct proportions** of proteins, fats, carbohydrates, vitamins, mineral salts, roughage, and water. The daily energy requirement of individuals varies according to age, sex, body size, growth, and physical activity.

ROUGHAGE

Everything we eat is not broken down and absorbed in the alimentary canal. Some food always remains undigested. This indigestible food is very important for our health because it provides **roughage**. It also adds bulk or fibres to the food. The undigested food ultimately passes out of our body as **faeces**. Roughage consists mainly of cellulose, from the plant materials we eat, and induces **peristalsis** (waves of contraction passing along the intestine which push along its contents). It prevents constipation and ensures proper bowel movements. By including many green vegetables and fruits in our diets, we not only obtain vitamins and mineral salts but also provide our bodies with the required roughage.

SECTION 3: HOW ANIMALS OBTAIN THEIR FOOD

Living organisms which are not dependent on any other organism for their food are known as **autotrophs**. Green plants are autotrophs, being the only living organisms other than a few bacteria which can independently manufacture their food from simple inorganic substances (like carbon dioxide and water) during the process of photosynthesis. This method of nutrition is known as **autotrophic nutrition.**

Animals are **heterotrophs**, since they cannot manufacture their own food. They are dependent on other living or dead organisms for their food. **Herbivorous** animals like goats, elephants, and rabbits eat nothing but plants, whereas **carnivorous** animals like lions, wolves, leopards, and dogs, are mainly flesh-eating animals. **Scavengers,** like the vulture, eat the flesh of dead animals. They are carrion eaters, and wait for old and injured animals to die, or depend upon the remains of the kill of the carnivorous animals. **Omnivorous** animals, like man, eat plants as well as animals, and have no specific preference. **Parasitic** animals live in or on the bodies of other living animals and plants and obtain their food directly from them. For example, tapeworms live in the intestine of man and rat-fleas live on the body of a rat and suck its blood.

FOOD CHAINS

All animals feed heterotrophically; that is, they do not combine simple inorganic substances within themselves to obtain food, but depend on other organisms to provide them organic food material. Large carnivorous animals like the tiger feed on smaller animals like deer, which, in turn, are herbivorous. Among human beings, non-vegetarians feed on the flesh of lambs and chickens, which, in turn, feed on plants and plant seeds, respectively. We find that in Nature, the nutritional habits of animals follow the pattern of **food chains**. Larger animals feed on smaller ones, the smaller ones on still smaller ones, and so on, until we arrive at the smallest animal in the chain which feeds on plants. Thus, we find that all animal food chains lead back to plants. The green plants are referred to as the producers, and the animals as the consumers. Herbivores are **primary consumers** and carnivores **secondary consumers**. Therefore, we conclude that ultimately all living organisms which feed heterotrophically depend on autotrophic green plants for their food.

We now give some common food chains, beginning with plants and ending with complex higher animals:

(1) Algae → water-fleas → *Hydra*.
(2) Diatoms (microscopic plants floating in sea water) → *Crustacea* → fishes → man.
(3) Seeds → field mice → cats and owls.
(4) Grass → sheep → human beings.
(5) Garden plants → aphids (green flies) → lady-bird beetles → spiders → tits and warblers → owls and hawks.
(6) Grass → grasshoppers → frogs → snakes → hawks.

METHODS OF NUTRITION

Depending upon the form or the state of food obtained by animals, there are two methods of nutrition: **holozoic nutrition** and **parasitic nutrition.**

Holozoic nutrition is the characteristic method of feeding adopted by most herbivores, carnivores, omnivores, and carrion eaters. Most of them take in solid food, except such insects as house-flies, mosquitoes, and spiders. The food that is ingested is complex, insoluble, and non-diffusible. In the digestive organs, this form of food is broken down, digested, or hydrolysed by certain chemicals called enzymes and changed to simple, soluble, and diffusible substances. These substances are then absorbed and used up by the animals for growth and repair of body tissues, and are also oxidised to release energy during respiration. The undigested residues or wastes of the food (or the food which cannot be digested) are discharged from their body in the form of faeces.

Thus, in animals which have a holozoic mode of nutrition, five processes are involved in making use of the available food: (1) **ingestion:** taking in of food; (2) **digestion**: converting it into a simple, soluble, and diffusible form with the help of enzymes; (3) **absorption**: the diffusion of the digested food into body fluids, such as blood and lymph, for transportation to all parts of the body; (4) **assimilation**: using the food materials and incorporating these in the cells themselves; and (5) **egestion**: throwing out the food substances that cannot be digested and absorbed in the form of faeces.

In **lower animals**, such as *Amoeba* and *Paramecium*, these processes are carried out in a simple and efficient way without any definite organs, but, in **higher animals**, such as insects, earthworms, snails, fishes, frogs, reptiles, birds, and mammals, there are definite organs to carry out these processes.

Parasitic nutrition occurs in some animals which live on or within the bodies of other living organisms. They suck or absorb their food directly from the bodies of the host organisms. Such animals are called **parasites**. In the relationship between parasites and hosts, the former are always the gainers, whereas the latter are always the losers. Sometimes, but not always, parasites harm their hosts to the extent of causing their death. Examples of parasitic nutrition are given in Table 19.2.

TABLE 19.2 SOME COMMON PARASITES AND THEIR HOSTS

PARASITES	HOST
Rat-flea	Rat
Female *Anopheles* mosquito	Human beings
Tapeworm	Human beings
Malarial parasite	Human beings
Liver fluke	Sheep

Animal parasites which live inside the bodies of their hosts are called **internal parasites** or **endoparasites**. Examples are tapeworms and roundworms, which are found inside the intestines of human beings. *Entamoeba* (which causes amoebic dysentery) is also an intestinal parasite, as also the malarial parasite which is present in the liver and blood cells of human beings. Endoparasites remain surrounded by the food already digested by the host and absorb it directly through the surface of their bodies.

Animal parasites which live on the surface of the host's body are known as **external parasites** or **ectoparasites**. Examples are bed bugs, lice, aphids, mosquitoes, leeches, fleas, ticks, and mites. The category of ectoparasites includes many insects which affect our personal life, our crops, our foods, and ultimately our health. They are dangerous because they carry disease-producing microbes within them, e.g., the female *Anopheles* mosquito, which is an ectoparasite of man, may carry *Plasmodium* (the malarial parasite), which is responsible for causing **malaria**. Again, rat-fleas which are ectoparasites of rats, carry *Bacillus pestis*, the bacteria which cause **plague**.

SECTION 4: DENTITION IN MAMMALS

TEETH

Mammals use their teeth to break up food into small pieces. There is a great diversity in the number, size, and shape of the teeth found among mammals and this is related to the type of food that is eaten. In spite of the apparent variations, all teeth have the same essential structure.

Structure: Each tooth is firmly sunk into a pit, which is called the **tooth socket**, and is located in the jaw bone [Fig. 19.1]. Each tooth consists of two main parts: (1) the **root**, which is the hidden part of the tooth that lies below the gum line and (ii) the **crown**, which is the visible part of the tooth that lies above the gum line.

The crown is covered on the outside by **enamel**, which is the hardest substance produced within an animal's body. It protects the internal parts of the tooth and provides an efficient surface for cutting and grinding food.

A tooth is held firmly in the tooth socket by means of a thin layer of bone-like material called **cement**. The greater part of a tooth is made up of a hard bone-like material called **dentine**. Each tooth has a hollow central cavity called the **pulp cavity**, which is filled with a soft connective tissue called **pulp**. The pulp contains sensory nerve endings, connective tissue, and blood capillaries. These capillaries bring oxygen and food which enable the tooth to grow. The nerve endings make the tooth sensitive to external stimuli such as cold and produce the sensation of pain. A narrow opening at the base of a tooth allows the entry of nerve fibres and blood capillaries into the pulp cavity. In most mammals this opening is almost closed (but is large

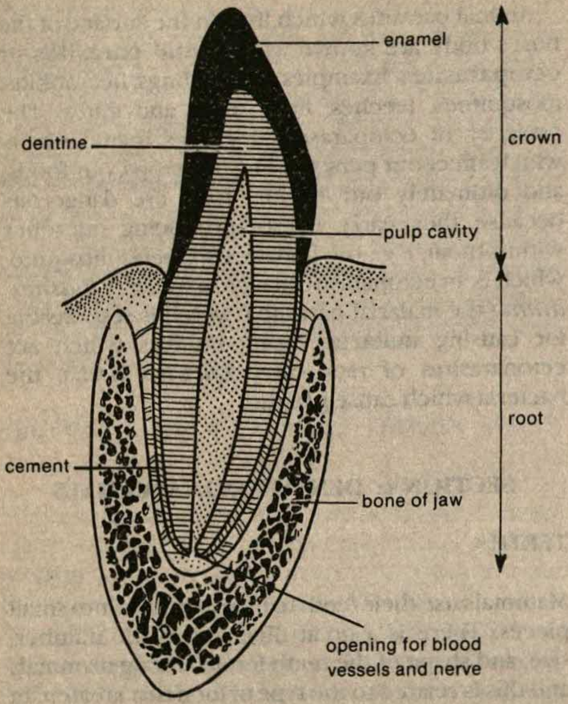


FIG. 19.1 Longitudinal section through mammalian tooth, to show structure

enough to let nerve fibres and blood capillaries pass through it), and prevents teeth from growing throughout one's lifetime.

An adult human being has 32 teeth, and these are known as **permanent teeth**. There are four different types of teeth in a complete set of teeth:

(i) **Incisors**: There are four incisors each in the upper and lower jaws. These teeth are chisel-shaped for biting into foodstuffs.

(ii) **Canines**: There are two canines each in the upper and lower jaws. These are specialised pointed teeth designed for gripping and tearing the food.

(iii) **Premolars**: There are four premolars each in the upper and lower jaws. These teeth have flat and large surfaces bearing small grooves and ridges. They serve to crush and grind the food.

(iv) **Molars**: There are six molars each in the upper and lower jaws. Like the premolars they also have flat surfaces with small projections which are suitable for grinding and crushing the food.

The number and type of teeth for different mammals can be conveniently expressed as a dental formula, in which the letters stand for the type of teeth, while the numerals refer to the number of teeth in each half of the jaw. The dental formula for a human adult is:

$$i\,\frac{2}{2},\quad c\,\frac{1}{1},\quad pm\,\frac{2}{2},\quad m\,\frac{3}{3},\qquad \text{total 32.}$$

Human beings, like all other mammals, develop two sets of teeth in a lifetime; the first set consists of 20 **milk teeth** (no molars) which fall during childhood, generally after the age of five and are replaced by a set of 32 **permanent teeth**. The dental formula for a set of milk teeth in the human child is:

$$i\,\frac{2}{2},\quad c\,\frac{1}{1},\quad pm\,\frac{2}{2},\quad m\,\frac{0}{0},\qquad \text{total 20.}$$

DENTITION IN MAMMALS

The teeth of different mammals are designed according to the type of food consumed. There are three main categories of specialised teeth:

(a) Teeth belonging to human beings (**omnivorous**).

(b) Teeth belonging to mammals like dog, tiger, and wolf (**carnivorous**).

(c) Teeth belonging to mammals like rabbit and sheep (**herbivorous**).

DENTITION IN HUMAN BEINGS (OMNIVOROUS)

Human beings eat both animal and plant foods, and are known as **omnivores**. The top and bottom incisors overlap when the jaws are clenched and can therefore bite and cut off food [Fig. 19.2]. Canines are used to grip the food, while premolars and molars present in the two jaws meet to crush and grind it. The joint between the lower jaw and the upper jaw, at the two corners, allows both sideways and forward movement required for grinding the food efficiently.

DENTITION IN THE DOG (CARNIVOROUS)

The dental formula of the dog is:

$$i\,\frac{3}{3},\quad c\,\frac{1}{1},\quad pm\,\frac{4}{4},\quad m\,\frac{2}{3},\qquad \text{total 42.}$$

The dog has twelve incisors which are small and sharp, and are used for scraping meat off bones [Fig. 19.3]. The incisors are followed by four canines,

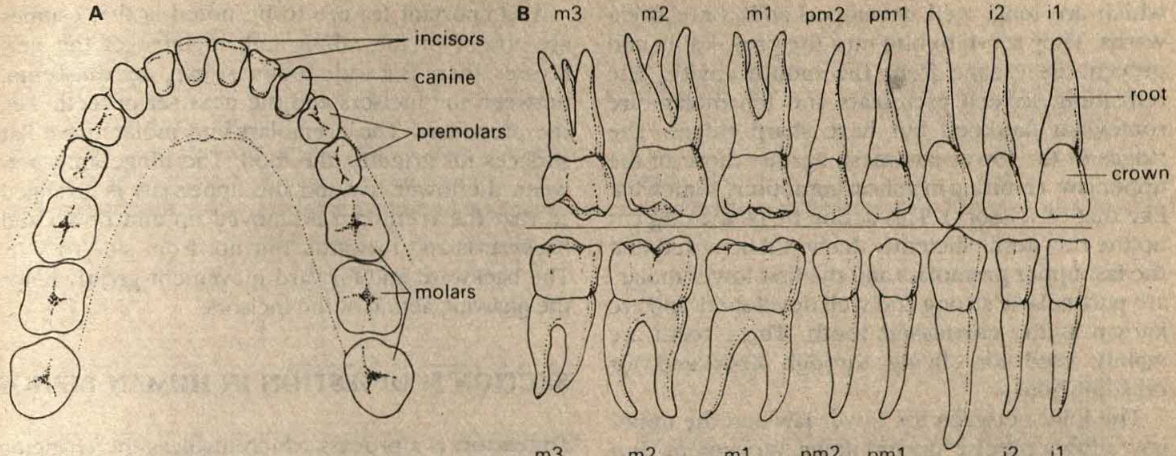


FIG. 19.2 Dentition in man, showing arrangement of teeth on jaw (left) and shapes of various types of teeth (right)

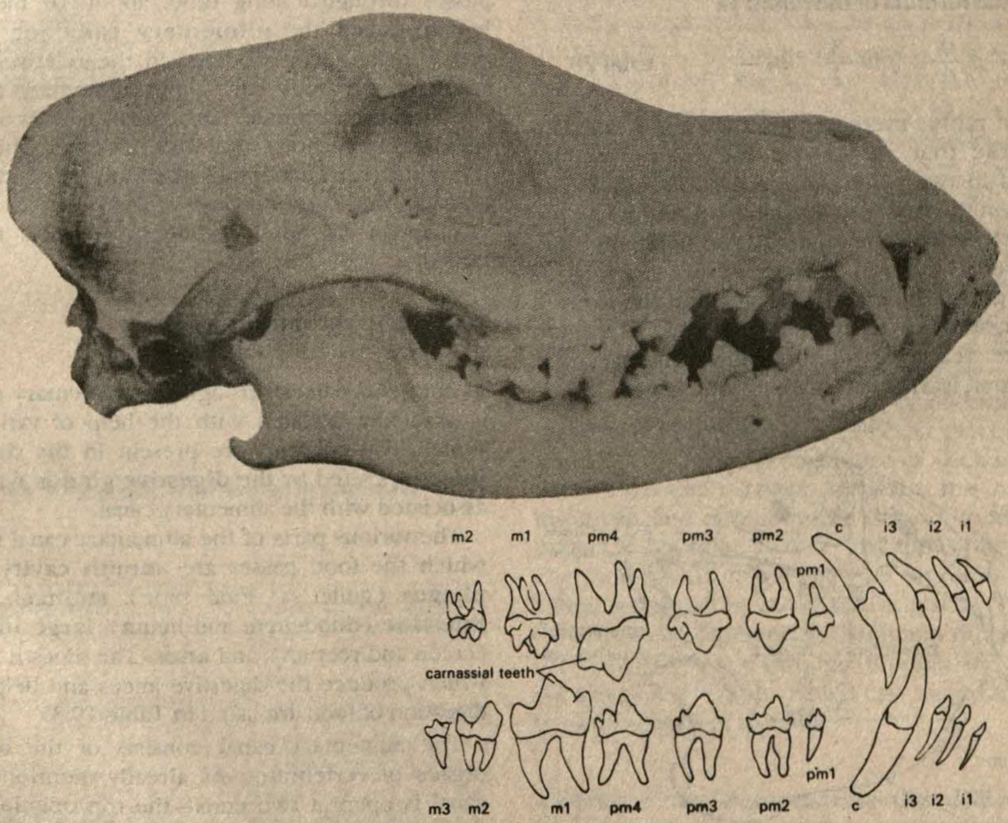


FIG. 19.3 Dentition in dog, showing skull (above) and shapes of various types of teeth (below)

which are long, well developed and curve backwards. They serve to bite into the prey, kill it, and prevent its escape from the mouth cavity. The remaining sixteen premolars and ten molars are somewhat flattened but have sharp ridges. The ridges in the lower jaw mesh against those of the upper jaw, resulting in a shearing action (somewhat like that of scissors). This action helps the dog cut up the raw flesh efficiently. It should be noted that the last upper premolars and the first lower molars are particularly strong and well developed, and are known as the **carnassial teeth**. These teeth are mainly used for slicing through flesh and for crushing bones.

The joint between the lower jaw and the upper jaw allows precise up-and-down movement, but not any forward or sideways movement; the latter would make the shearing and snapping actions less efficient.

DENTITION IN THE RABBIT (HERBIVOROUS)

The dental formula of the rabbit is:

$$i\,\frac{2}{1},\quad c\,\frac{0}{0},\quad pm\,\frac{3}{2},\quad m\,\frac{3}{3},\qquad \text{total 28.}$$

In the rabbit there are six incisors in all [Fig. 19.4]. The four incisors in the upper jaw are arranged in two pairs, one behind the other. The incisors in the front are long and curved, while the ones further back are smaller. The upper incisors bite against the lower ones while nibbling or cutting grass. The enamel is thicker at the front of the incisors than at the sides or back. The teeth therefore wear away more quickly at the back than at the front, leaving flat, sharp cutting edges.

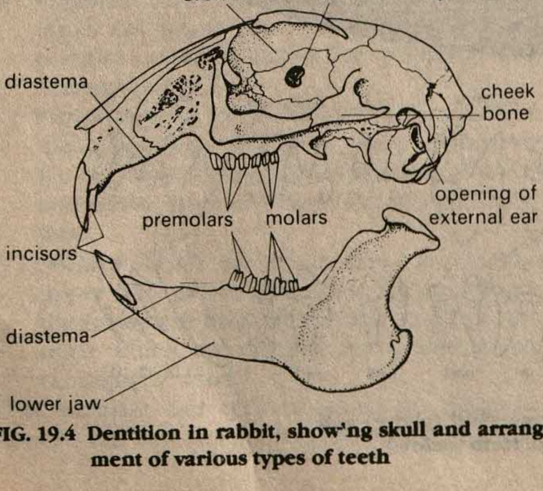


FIG. 19.4 Dentition in rabbit, showing skull and arrangement of various types of teeth

An important feature to be noted is that canines are absent in the rabbit and, in most of the herbivores, there is a wide toothless gap, the **diastema**, between the incisors and the next set of teeth, i.e., the premolars. The premolars and molars have flat surfaces for grinding the food. The hinge joint between the lower jaw and the upper jaw is arranged so that the teeth can be moved up and down and backwards and forwards, but not from side to side. The backward and forward movement greatly helps the gnawing action of the incisors.

SECTION 5: DIGESTION IN HUMAN BEINGS

Digestion is a process which involves the changing of complex, insoluble, and non-diffusible foods into simple, soluble, and diffusible substances by the action of **enzymes**. The human **digestive system** includes all the organs concerned with ingestion, digestion, absorption (of digested foods) and egestion (of undigested foods). The food that we eat passes through a long tube, about 10 metres in length, called the **alimentary canal** or gut. In order to be accommodated in the relatively small space of the body cavity, the alimentary canal is coiled and convoluted. This canal, narrow in some regions of the body and wide in others, begins at the mouth, through which the food is ingested, and ends at the anus, through which the undigested remains of the food are egested in the form of faeces.

THE PROCESS OF DIGESTION

As the food passes through the alimentary canal, it is gradually digested with the help of various enzymes. The enzymes are present in the **digestive juices** secreted by the **digestive glands** which are associated with the alimentary canal.

The various parts of the alimentary canal through which the food passes are: **mouth cavity, oesophagus** (gullet or food pipe), **stomach, small intestine** (duodenum and ileum), **large intestine** (colon and rectum), and **anus**. The digestive glands which produce the digestive juices and help in the digestion of food are listed in Table 19.3.

The alimentary canal consists of the digestive organs of vertebrates. As already mentioned, this canal is open at two ends—the top opening being the mouth and the bottom opening the anus.

The alimentary canal lies in the body cavity, which is surrounded by the body wall. A simple glass tube

TABLE 19.3 DIGESTIVE GLANDS AND THEIR JUICES

DIGESTIVE GLAND	LOCATION IN BODY	JUICE SECRETED	WHETHER THE DIGESTIVE JUICE CONTAINS DIGESTIVE ENZYMES OR NOT
Salivary glands	Around the mouth cavity	Saliva	Yes
Gastric glands	On the wall of the stomach	Gastric juice	Yes
Liver	Below the diaphragm on the right side	Bile	No
Pancreas	Between the stomach and the duodenum	Pancreatic juice	Yes
Intestinal glands	On the wall of the ileum	Intestinal juice	Yes

model shown in Fig. 19.5 illustrates this arrangement in the body. The parts labelled in Fig. 19.5 have the following equivalents in the human body:

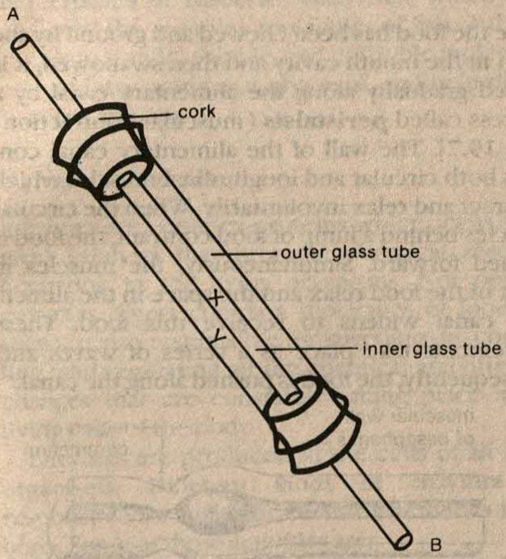


FIG. 19.5 Simple glass tube model of alimentary canal

IN THE FIGURE	IN THE HUMAN BODY
1. A	Mouth
2. B	Anus
3. Space X in the inner glass tube	Cavity of the alimentary canal where digestion and absorption of food take place.
4. Space Y in the outer glass tube that surrounds the inner glass tube	Body cavity containing various organs of the body.

In this model, any substance that enters X at A will straightaway come out through B. Similarly, the food entering the alimentary cannal at the mouth will straightaway come out of the anus, if it is not absorbed during its movement from one end to the other. Even if the food remains in the alimentary canal (or in X in the model) for some time, it cannot be of any use unless it is transported to the various organs of the body for assimilation. Most of the organs lie in the body cavity (or in space Y in the model), i.e., outside the alimentary canal. The food cannot pass directly from the alimentary canal to the various organs in the body through the canal wall (or from X to Y through the glass wall of the inner tube in the model). Body fluids such as **blood** and **lymph** are required to transport the food from the alimentary canal to the various parts of the body, which is then used for different purposes.

Most of the foods taken in by animals are in a complex, insoluble, and non-diffusible form and body fluids such as blood and lymph are incapable of absorbing and then transporting this form of food to various parts of the body. Under these circumstances, this form of food proves useless to the body. In order to make it useful, this complex, insoluble, and non-diffusible form of food is converted to a simple, soluble, and diffusible form by chemical agents called enzymes secreted into the alimentary canal by the digestive glands. Thus, the food has to be **digested** so that it may diffuse out of the alimentary canal through its boundary wall into the blood and lymph, which can then transport it to various parts of the body.

Activity 1: To demonstrate the diffusion of food substances through the alimentary canal wall.

Prepare a 15-cm-long bag of sausage skin (lining of

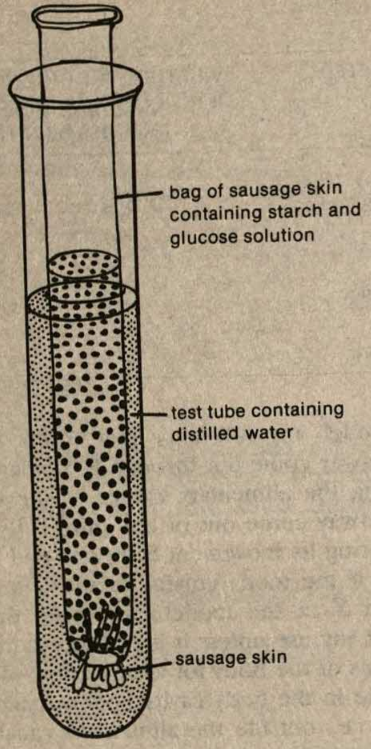


FIG. 19.6 Experimental setup to demonstrate diffusion of food substances

pig's intestine) as shown in the figure [Fig. 19.6] and pour into it 5 ml of a 5% starch solution and 5 ml of a 5% glucose solution. Wash the bag from outside with water to remove any starch and glucose which might have spilled over on to the outer surface during the filling operation. Suspend the bag containing this mixture in a large test tube containing distilled water.

Immediately after immersing the bag in distilled water, take two samples of this water; test one sample for the presence of starch and the other for the presence of glucose. Neither starch nor glucose will be detected. Again, after half an hour, test the distilled water samples for the presence of starch and glucose. This time the distilled water will contain only glucose. Obviously, glucose has diffused out of the bag into the distilled water, but not starch (whose molecules are complex and insoluble). In a similar manner, only simple and soluble molecules of food substances can diffuse out from the cavity of the alimentary canal through its lining into the blood and lymph.

Of the six classes of food substances taken in by animals, only three (**vitamins, mineral salts,** and **water**) are simple, soluble, and diffusible. These food substances need not be digested since they can directly and easily diffuse out through the lining of the alimentary canal into the blood for transportation. The other three classes of food, namely, **proteins, starches,** and **fats**, are insoluble and non-diffusible, and they definitely need to be digested before they can be absorbed by the blood and then transported to various parts of the body.

After digestion, the proteins are converted to **amino acids**; the starches to simple **sugars** (like **glucose** and **fructose**); and the fats to **fatty acids** and **glycerol**.

MOVEMENT OF FOOD THROUGH THE ALIMENTARY CANAL

Once the food has been chewed and ground by the teeth in the mouth cavity and then swallowed, it is moved gradually along the alimentary canal by a process called **peristalsis** (muscular contraction) [Fig. 19.7]. The wall of the alimentary canal contains both circular and longitudinal muscles which contract and relax involuntarily. When the circular muscles behind a lump of food contract, the food is pushed forward. Simultaneously, the muscles in front of the food relax and the space in the alimentary canal widens to receive this food. These movements take place as a series of waves and, consequently, the food is pushed along the canal.

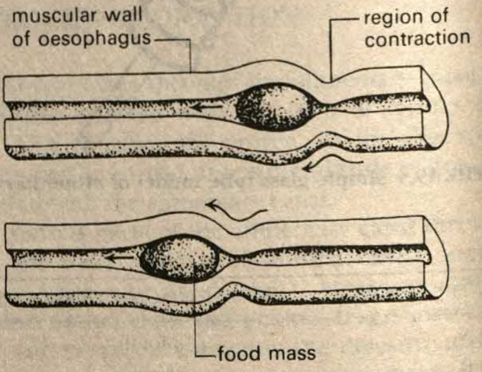


FIG. 19.7 Peristalsis in the alimentary canal

Activity 2: To demonstrate peristalsis.
Take a 25-cm-long rubber tube and a glass marble of a suitable size, i.e., which can just be squeezed into the hollow of the rubber tube. If pressure is exerted on that portion of the rubber tube just behind the marble (similar to the narrowing of the alimentary

canal region behind the food by the contraction of muscles), the marble will be pushed forward along the hollow of the rubber tube.

DIGESTIVE ENZYMES

There are three kinds of digestive enzymes, whose functions are as follows:

(i) **Proteases** or **proteolytic enzymes**, which convert the complex molecules of **proteins** into simple, soluble, and diffusible molecules of **amino acids** and help digest proteins.

(ii) **Amylases** or **amylolytic enzymes**, which act upon complex molecules of **carbohydrates** and convert them to simple, soluble, and diffusible molecules of **sugars** like **glucose** and **fructose**, and help digest carbohydrates.

(iii) **Lipases** or **lipolytic enzymes**, which convert the complex molecules of **fats** and **oils** into simple, soluble, and diffusible molecules of **fatty acids** and **glycerol**, and help digest fats and oils.

NATURE OF ENZYMES

Enzymes are complex proteins which act as biological catalysts that promote chemical reactions occurring in the living organisms. Not only do enzymes digest complex molecules of food, but they are also responsible for speeding up, controlling, and regulating all the chemical activities and changes that are constantly taking place in the living cells of the body.

Enzymes are produced in the cells of all living organisms. Different kinds of enzymes are responsible for different chemical activities in the body. Some of these activities are:

(1) Digestion of food by **hydrolysing or digestive enzymes**.

(2) Conversion of excess of food substances into a form in which they can be stored in the body; for instance, if our diet includes excessive carbohydrates, the digested excess is changed into glycogen and stored in the liver and in the muscle cells. Such a conversion is brought about by **condensation enzymes**.

(3) Release of energy from food during the process of respiration in living cells with the help of **respiratory enzymes**.

In brief, all the chemical reactions going on in the living cells, which constitute **metabolism**, are controlled by enzymes.

PROPERTIES OF ENZYMES

The main characteristics possessed by all enzymes are:

(1) Enzymes work within a **narrow range of temperature**, i.e., between 35°C and 40°C. At high temperatures, they are rendered inactive or destroyed. When the temperature decreases below this range, the reactions which enzymes control gradually slow down and ultimately come to a halt.

(2) Enzymes act as catalysts within living cells (hence they are called **biocatalysts**) and speed up the chemical reactions occurring in them, which would otherwise be slow. Like chemical catalysts, a small quantity of an enzyme is sufficient to bring about a large amount of chemical change. Enzymes are not destroyed during catalysis and so can be reused.

(3) Enzymes are sensitive to pH (acidity or alkalinity). Every enzyme functions most efficiently over its own range of pH.

(4) The action of any particular enzyme is specific; that is, it acts only on one kind of substance. For example, **proteases**, which digest proteins, will not have any effect either on carbohydrates or on fats and oils.

(5) Enzymes are required only in small quantities and each enzyme always produces the same end product.

DIGESTION ALONG THE ALIMENTARY CANAL

The mouth cavity: Digestion begins when a food material enters the mouth cavity. Here, the food is **masticated** or broken down into smaller particles by the teeth in order to provide more surface area for the action of enzymes. As the food is masticated, it is thoroughly mixed up with **saliva**, which is secreted by three pairs of **salivary glands** [Fig. 19.8]. Saliva is constantly secreted in small quantities in order to keep the mouth cavity moist. When there is food in the mouth cavity, the rate of saliva secretion is greatly increased. Even the thought or smell of some palatable food stimulates the salivary glands to secrete more saliva. Saliva contains an amylolytic enzyme called **salivary amylase** or **ptyalin** which converts starch in the food to a sugar called **maltose**. In addition to digesting starch, saliva moistens the food and **lubricates** it for easier swallowing.

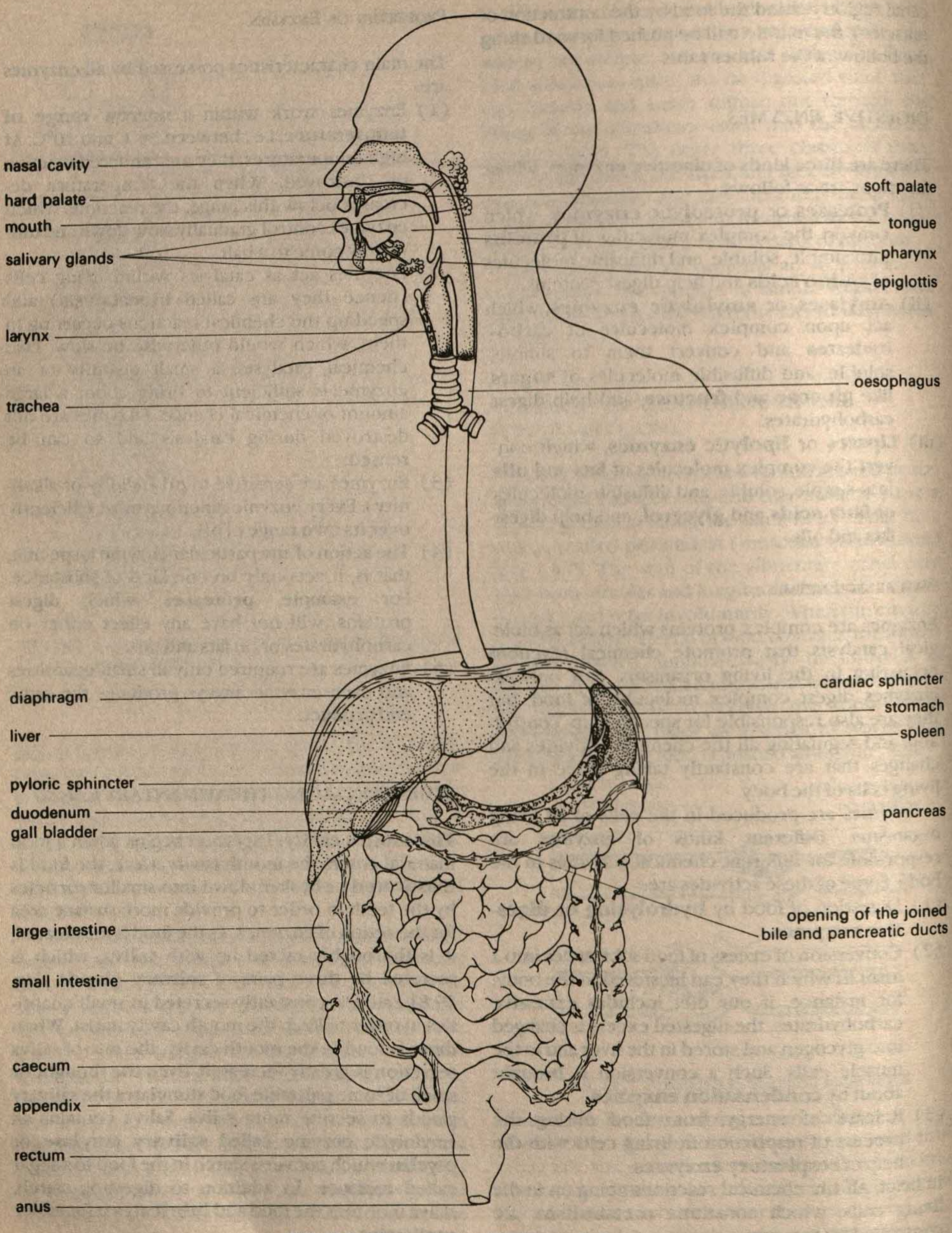


FIG. 19.8 Alimentary canal in human beings

The **tongue** has special sensory cells in its taste buds and the dissolved food substances stimulate these cells to create a sensation or feeling of **taste**.

Activity 3: To demonstrate the effect of ptyalin.
Take a small piece of *chapati* or bread, and masticate it thoroughly for at least five minutes. In the beginning, it does not taste sweet, but within a few minutes of thorough mastication, it begins to do so. This is because the starch has been converted to sugar by the action of ptyalin present in the saliva.

Swallowing: When the food has been thoroughly masticated and mixed with the saliva, the tongue rolls it into a ball (bolus) and thrusts it into the **pharynx**. From the pharynx, the food is pushed into the **oesophagus** (or food pipe) through which it is moved by peristalsis and finally reaches the stomach. The function of the valve-like **epiglottis** is to close the opening into the larynx so as to prevent food from entering the trachea.

The stomach: The stomach lies on the left side in the upper part of the abdominal cavity, below the diaphragm. It is a large, bag-like structure with thick muscular walls provided with **gastric glands**. The food remains in the stomach for 2-3 hours, depending upon the type and amount taken. The **gastric juice**, produced by the chief (or peptic) cells in the wall of the gastric glands, contains **hydrochloric acid** and three digestive enzymes. The hydrochloric acid produced by oxyntic cells in the gastric glands helps kill the bacteria which may be present in the food and also provides the acidic medium essential for the activity of the enzymes in the gastric juice. The three digestive enzymes are:

(i) **Pepsin**, which changes **proteins** to **peptones**, which have simpler molecules.
(ii) **Rennin**, which coagulates the soluble proteins of milk, namely, caseinogen, into insoluble casein, which is then acted upon by **pepsin**.
(iii) **Gastric lipase**, which digests the smaller chunks and drops of **fats** and **oils** and changes them to **fatty acids** and **glycerol**.

Gastric juice is always present in the stomach, but the presence of food in the stomach stimulates the gastric glands to produce more gastric juice. The muscular walls of the stomach contract and relax rhythmically, thus churning the food and mixing it thoroughly with the gastric juice. From the stomach, the partly digested food, called **chyme**, reaches the **duodenum** in small quantities. The passage of chyme into the duodenum is controlled by a ring of muscles, known as **pyloric sphincter**; thus, the chyme passes slowly into the duodenum.

THE SMALL INTESTINE

Digestion in the duodenum: The duodenum is the first part of the small intestine. Here, the food receives two digestive juices: **bile** from the **liver** and **pancreatic juice** from the **pancreas**.

Bile is produced in the liver and stored in the **gall bladder**, from where it is carried to the duodenum by the **bile duct**. Bile is **alkaline** and thus neutralises the acidic food to provide the alkaline medium necessary for the activities of the enzymes present in the pancreatic juice. Bile itself does not contain any enzymes; in fact, it contains **bile salts**, namely, **sodium taurocholate** and **sodium glycholate**, which emulsify fats by reducing their surface tension and causing them to break up into numerous tiny droplets. Emulsification increases their total surface area and leads to increased and rapid action of the enzymes which digest fats.

Activity 4: To demonstrate the formulation of an emulsion.
Take 15 ml of tap water in a large test tube. Add 1 ml of coconut oil or any other oil to it. The oil will form a large drop which floats on the surface of water. Cork the test tube and shake it vigorously. The single large drop of oil will not be visible any more; instead there will be a large number of small droplets suspended throughout the water. Oil has thus formed a suspension or **emulsion** in water, because the large drop of oil has been emulsified or broken down into many smaller droplets.

Activity 5: To calculate the surface area of a food substance.
Find the length L, breadth B, and height H of a loaf of bread. Calculate its surface area by the following formula:

$$2(L \times B) + 2(L \times H) + 2(B \times H)$$

Cut the loaf of bread into two equal halves. Calculate the surface area of each half in the same way as before and then find the sum total of the surface areas of the two halves of the loaf. You will find that this sum total is more than the surface area of the complete loaf.

When large drops of fats and oils are broken into smaller droplets or emulsified by the action of bile, they similarly provide more total surface area.

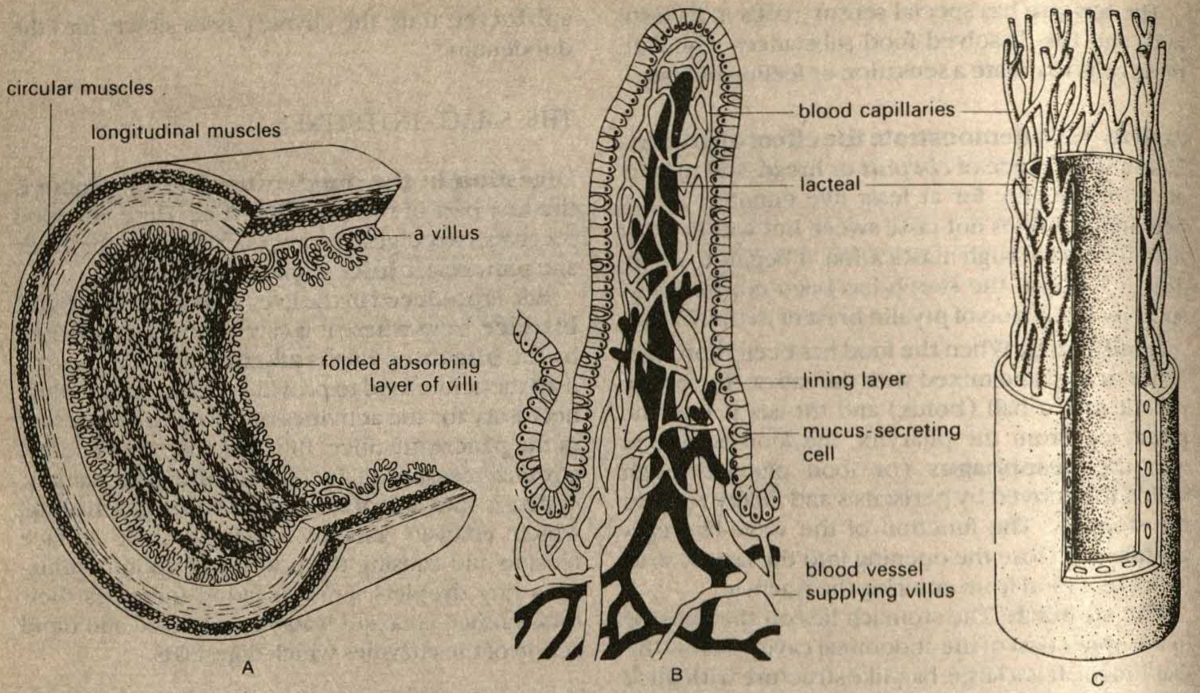


FIG. 19.9 (A) Intestinal wall lined with villi on inner surface; (*B*) longitudinal section through villus; and (*C*) stereogram of villus

The **pancreatic juice** contains three specific enzymes:

(1) **Pancreatic amylase**, which converts the remaining starch in the food to maltose.
(2) **Trypsinogen**, which is changed into active **trypsin** by the action of another enzyme, **enterokinase**, present in the intestinal juice. This then changes **peptones** into **amino acids**.
(3) **Lipase**, which converts emulsified **fats** and **oils** into **fatty acids** and **glycerol**.

Digestion in the ileum: The process of digestion which begins in the mouth cavity is completed in the **ileum** by the action of enzymes contained in the **intestinal juice** secreted by intestinal glands. The intestinal juice contains the following enzymes:

(1) **Enterokinase** (function just described).
(2) **Peptidase**, which converts the **peptones** to **amino acids**, thus completing the digestion of proteins.
(3) **Maltase**, which further changes **maltose** to **glucose**.
(4) **Invertase** (or sucrase) which converts **sucrose** to **glucose** and **fructose**.
(5) **Lactase**, which converts **lactose** (milk sugar) to **glucose** and **galactose**.
(6) **Lipase**, which converts the remaining emulsified **fats** to **fatty acids** and **glycerol.**

Absorption of digested food: In the ileum, the digested foods, mineral salts, vitamins, and water are absorbed by the **blood** and **lymph**. Absorption takes place by the diffusion of simple, soluble, and diffusible forms of food into the blood and lymph. The following characteristics of the ileum are important adaptations which make its absorbing properties better:

(1) It is extremely long and presents a large absorbing surface to the food.
(2) Its inner surface is greatly increased by the presence of thousands of minute finger-like projections called **villi** [Fig. 19.9].
(3) Its lining of epithelium is very thin, leading to the rapid diffusion of the substances.
(4) It has a dense network of blood capillaries in each villus.
(5) It has a **lacteal** or lymph vessel in each villus.

Digested proteins and carbohydrates, as well as vitamins, mineral salts, and water, are absorbed by the blood in the blood capillaries, while the digested fats and oils are absorbed by the lymph in the lacteals. Later on, however, the digested fats and oils are transferred from the lymph to the blood, which transports all the food substances to various parts of the body.

THE LARGE INTESTINE

The **large intestine** consists of the **caecum**, with the **appendix**, the **colon** (divided into the ascending colon, the transverse colon, the descending colon, and pelvic parts), and the **rectum**. By the time the food reaches the large intestine, the digestible and diffusible contents have been absorbed in the ileum. What remains is excess water and indigestible matter, largely cellulose and vegetable fibres (the **roughage**), bacteria, mucous, and dead cells broken off from the lining of the alimentary canal. The large intestine absorbs much of the water from the undigested residues, which are thus changed to semi-solid **faeces**. The faeces are temporarily stored in the **rectum** and egested through the anus at intervals.

The fate of digested food: It would be worthwhile to discuss what happens to the different constituents of food after digestion. The **digested proteins** are transported, as amino acids, by blood plasma, to various parts of the body where they are put to use by **all** the cells for building up more protoplasm, which is required for growth. Excess amino acids cannot be stored in the body and are therefore converted to **urea** and **glucose**; urea is excreted and glucose is used in respiration.

The **digested carbohydrates**, carried by the blood as glucose and fructose, are utilised by **all** the cells of the body to obtain energy during respiration. The excess carbohydrates are stored as **glycogen** in the liver and the muscles. The stored glycogen can be reconverted to glucose and released into the blood whenever necessary.

The **digested fats and oils** are used by **all** the cells of the body. Excess fat is stored as **subcutaneous fat** reserve under the skin for insulation against heat and for obtaining energy when the need arises.

Activity 6: To construct a working model of the ileum and to demonstrate the digestion of starch and the diffusion of the products of digestion.

Take two 15-cm-long pieces of sausage skin (lining of pig's intestine) and label them as A and B. Seal one end of each piece by firmly securing it with a

TABLE 19.4 DIGESTION OF FOOD IN HUMAN BEINGS

DIGESTIVE GLAND(S)	DIGESTIVE JUICE	ENZYME(S)	ACTION
Salivary glands	Saliva (Slightly alkaline)	Salivary amylase (ptyalin)	Starch → maltose
Gastric glands	Gastric juice with hydrochloric acid	Pepsin Rennin Gastric lipase Gastric lipase	Proteins → peptones, Coagulates milk proteins (caseinogen → casein) Fats → fatty acids and glycerol
Liver	Bile (alkaline)	Bile salts (**not** enzymes)	Emulsifies fats and oils (larger drops → tiny droplets)
Pancreas	Pancreatic juice (alkaline)	Trypsinogen	Peptones → amino acids (with the help of enterokinase in the ileum)
		Pancreatic amylase	Starch → maltose
		Pancreatic lipase	Emulsified fats → fatty acids and glycerol
Intestinal glands	Intestinal juice (alkaline)	Enterokinase	Trypsinogen → trypsin
		Intestinal amylase	Starch → maltose
		Peptidase	Peptones → amino acids
		Maltase	Maltose → glucose
		Sucrase	Sucrose → glucose and fructose
		Lactase	Lactose → glucose and galactose
		Lipase	Emulsified fats → fatty acids and glycerol

thread [Fig. 19.10]. In skin A, place a 1% starch solution. In skin B, place a mixture of 1% starch solution and a solution made by dissolving two tablets of Taka Diastase in 10 ml of water. Wash the skins on their outer side to remove any starch solution which might have been spilled during the filling operation. Now, suspend each skin in a test tube containing distilled water so that the part of each skin filled with solution is completely immersed. Place the entire apparatus in a region where the temperature is about 37°C. After about three hours, test the water in each test tube for the presence of starch and sugar.

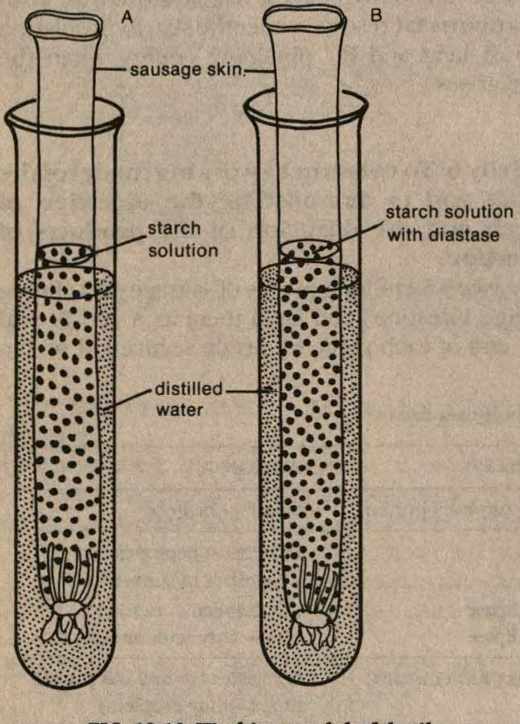


FIG. 19.10 Working model of the ileum

You will observe that the distilled water in the test tube around skin A does not show the presence of either starch or sugar. However, the water around skin B does indicate the presence of sugar, but not of starch. What do these two observations reveal about the action of the enzyme diastase on starch? The group of enzymes called diastases is also called amylases, which you have already come across. How do these two observations show that complex molecules cannot, while simple molecules can, diffuse through a membrane like the sausage skin? Your conclusion in this experiment will be true for the digestive process in the ileum also, because a similar process of breakdown and diffusion occurs there.

Activity 7: To demonstrate the digestive action of saliva on starch.

Collect some of your own saliva in a test tube after rinsing your mouth cavity to remove any traces of food. Then, take equal quantities (say, 2 ml) of a 1% starch solution separately in two other test tubes, which are labelled A and B. Do not add anything to test tube A, but add saliva to test tube B. Leave the tubes in a warm room. After one hour, test the contents of each tube for the presence of starch and sugar. You will observe that the contents of A show the presence of starch but not of sugar, whereas the mixture in B shows the presence of sugar but not of starch. What do these two observations indicate about the action of saliva on starch?

Activity 8: To show the action of protease on proteins.

Take the albumen of one egg and stir it into 500 ml of distilled water. Boil this mixture and then filter it. Pour 5 ml of this filtrate X, which is in the form of a cloudy suspension, into each of four test tubes labelled A, B, C, and D. Grind one small raw papaya with sand using a pestle and mortar. To this ground mixture, add about 100 ml of distilled water. Filter this solution to obtain filtrate Y.

To the filtrate X in the four test tubes, add the following:

Test tube A: Add 2 ml of Y.
Test tube B: Add 3 drops of dilute hydrochloric acid.
Test tube C: Add 2 ml of Y and 3 drops of dilute hydrochloric acid.
Test tube D: Add 2 ml of Y and 3 drops of sodium hydroxide.

Place all four test tubes in a beaker of water at about 37°C for about one hour. After this period, it is observed that the contents of only test tube C become **clear**; those of A, B, and D remain **cloudy**. This change from a cloudy suspension to a clear solution suggests that:

(i) the solid egg-white particles (**proteins**) have been changed to soluble products by the action of enzymes (**proteases**) in the papaya extract; and
(ii) the proteases have brought about this change only in an **acid medium**, since the enzymes have been ineffective in test tubes A and D.

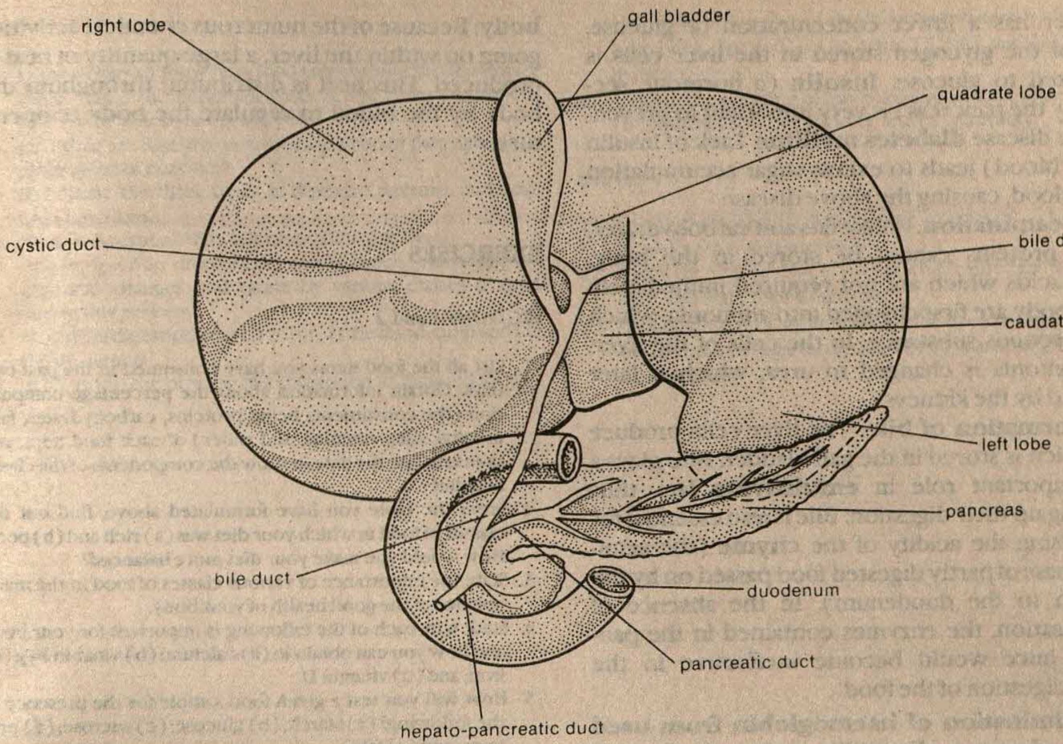


FIG.19.11 Relation between liver, gall bladder, pancreas and duodenum. (The liver has been turned back so that it can be viewed from beneath.)

SECTION 6: THE LIVER AND ITS FUNCTIONS

The **liver** is the largest gland of our body. It is situated on the right side of the abdominal cavity immediately below the diaphragm. The liver and the stomach partly overlap. The human liver is reddish brown in colour and weighs about 1.5 kg. It is divided into two portions called **lobes**. The right lobe is larger and is further divided into three smaller lobes. Between and underneath the two lobes lies the **gall bladder**. The gall bladder stores a greenish-coloured liquid called **bile** which is discharged down the bile duct at appropriate times. A number of small ducts arise in the liver. These ducts join to form a large duct which receives a branch called the **cystic duct** from the gall bladder. The main bile duct thus formed by the union of the cystic duct and the small ducts from the lobes of the liver merges with the pancreatic duct to form a short bile-pancreatic duct which opens into the duodenum.

The liver receives blood from the alimentary canal through the **hepatic portal vein**. It also receives blood from the aorta through the **hepatic artery**. Blood leaves the liver through a large vein called the **hepatic vein** which joins the inferior vena cava [Fig. 19.11].

FUNCTIONS OF THE LIVER

1. Regulation of blood sugar: The liver keeps the level of **glucose** in the blood between 80 and 150 mg per 100 cm^3 of blood. If the level falls below 40 mg per 100 cm^3 of blood, the brain cells are affected adversely, leading to convulsions and coma. On the other hand, if it rises above 160 mg per 100 cm^3 of blood, the kidneys are strained, i.e., they are overworked because the quantity to be excreted increases. The hepatic portal vein brings the digested food substances, including glucose, from the ileum to the liver. The cells of the liver convert the excess glucose in the blood (i.e., if it is more than the normal level) into an insoluble form called **glycogen** by the action of a hormone called **insulin** and store it. If the blood passing through the liver has a lower concentration of glucose, some of the glycogen stored in the liver cells is converted to glucose. **Insulin** (a hormone secreted by the pancreas) is very important in preventing the disease **diabetes mellitus**. Lack of insulin (in the blood) leads to excess sugar accumulation in the blood, causing the above disease.

2. Deamination: Unlike fats and carbohydrates, excess proteins cannot be stored in the body. Amino acids which are not required immediately by the body are first changed into ammonia, which is a poisonous substance. In the cells of the liver, this ammonia is changed to urea, which is later excreted by the kidneys.

3. Formation of bile: The liver cells produce bile which is stored in the gall bladder. Bile plays a very important role in **emulsifying** fats, thus speeding up their digestion. Bile is also essential for neutralising the acidity of the **chyme** (the semi-liquid mass of partly digested food passed on by the stomach to the duodenum). In the absence of neutralisation, the enzymes contained in the pancreatic juice would become ineffective in the further digestion of the food.

4. Elimination of haemoglobin from used red blood corpuscles: Millions of used red blood corpuscles are destroyed every day in the liver, spleen, and bone marrow. The haemoglobin of the red blood corpuscles is broken down by the liver cells into bile pigments—**biliverdin** and **bilirubin**. These are then excreted in the bile.

5. Storage of iron: The decomposition of the broken-down red blood corpuscles is completed in the liver, and the iron from their haemoglobin molecules is stored within its cells, for the formation of new haemoglobin, when required.

6. Formation of plasma proteins: Most of the proteins found in the blood plasma, including **fibrinogen**, are produced in the liver cells. Blood fails to clot in the absence of fibrinogen.

7. Detoxication: Due to the action of bacteria on amino acids, some foul-smelling and poisonous chemical substances (called **toxins**) are formed in the large intestine. These toxic substances are carried by the blood from the large intestine to the liver, where they are converted to harmless chemicals which are later excreted through the urine.

8. Storage of vitamins: The fat-soluble vitamins A and D are stored in liver cells. The liver also stores a product of vitamin B_{12} which is necessary for the formation of red blood cells in the bone marrow.

9. Distribution of heat throughout the body: Because of the numerous chemical activities going on within the liver, a large quantity of heat is produced. This heat is distributed throughout the body by the blood to regulate the body temperature.

EXERCISES

SECTIONS 1 and 2

1. List all the food items you have consumed in the past two days. Obtain information about the percentage composition (the constituents being proteins, carbohydrates, fats, mineral salts, vitamins, and water) of each food item, and then tabulate the data to show the components of the classified diet.
2. From the table you have formulated above, find out the classes of food in which your diet was (a) rich and (b) poor. How would you make your diet more balanced?
3. State the importance of various classes of food in the maintenance of the good health of your body.
4. State why each of the following is important for your body and how you can obtain it: (a) calcium; (b) vitamin B_{12}; (c) iron; and (d) vitamin D.
5. How will you test a given food sample for the presence of the following? (a) starch; (b) glucose; (c) sucrose; (d) proteins; and (e) fats.

SECTION 3

6. Explain the following terms with five examples of each: (a) autotrophs; (b) heterotrophs; (c) herbivores; (d) carnivores; (e) omnivores; and (f) scavengers.
7. (a) Explain, with the aid of three examples, the meaning of the term 'food chain'.
   (b) Which type of organisms are at the beginning of a food chain and why?
8. How does holozoic nutrition differ from parasitic nutrition? Give examples.
9. Describe each of the following processes: (a) ingestion; (b) digestion; (c) absorption; (d) assimilation; and (e) egestion.
10. (a) Name five parasites and their respective hosts, other than those mentioned in the text.
    (b) Distinguish, with the aid of two examples of each, between internal and external parasites.

SECTION 4

11. (a) Name the different types of teeth possessed by a human being.
    (b) What are the functions of each of these types?
    (c) How many of each type do we have as (i) children and (ii) adults?
12. With the aid of a labelled diagram, describe the structure of a human tooth.
13. Explain the meaning of the following terms: (a) diastema; (b) carnassial teeth; (c) milk teeth; and (d) permanent teeth.

SECTION 5

14. Draw a chart to show how food passes along the alimentary canal. Name the important parts of the canal and briefly discuss the functions of each part.
15. (a) What are digestive enzymes and how do they differ from other types of enzymes?
    (b) Name the three types of digestive enzymes and state their functions.
16. What is digestion? Why is it essential to our lives?
17. Briefly describe digestion in the stomach, indicating the chemical changes undergone by various classes of food during this process.
18. How does digestion take place in: (a) the duodenum and the (b) the ileum?
19. (a) Explain the process of a absorption of digested food.
    (b) What is the fate of the following materials after they have been digested? (i) proteins; (ii) fats; and (iii) carbohydrates.
20. Explain the meaning of the following terms: (a) peristalsis; (b) emulsification; (c) acidity; and (d) alkalinity.

SECTION 6

21. Locate the position of the liver in your body, and describe its appearance and structure.
22. Name the various blood vessels which enter and leave the liver, and state their functions.
23. Explain the following functions of the liver: (a) regulation of the quantity of sugar in the blood; (b) deamination; and (c) detoxication.

CHAPTER 20

The Circulatory System

SECTION 1: IMPORTANCE AND STRUCTURE OF THE CIRCULATORY SYSTEM

All complex and higher groups of animals, e.g., mammals, birds, reptiles, earthworms, and insects, need to transport materials from one part of the body to another in order to keep their life activities going, i.e., to stay alive. Some such materials are:

(a) **food substances** (absorbed in the ileum) to all the cells of the body;

(b) **oxygen** (absorbed in the lungs/skin/gills), again, to all the cells of the body;

(c) **carbon dioxide** (formed in the cells) to the lungs; and

(d) **wastes** and harmful chemical substances (formed during metabolism in the cells) to the organs concerned with their removal from the body.

To perform this vital activity, i.e., transportation, there is a **circulatory system** in the body which primarily functions to supply food substances and oxygen to all the cells and to remove wastes formed in them. In addition, the circulatory system transports **hormones** (produced by the endocrine glands) to various parts of the body, provides a strong defence for the body, and helps regulate **body temperature** in **homoiothermic** (or warm-blooded) animals (like mammals) and birds.

The circulatory system functions due to the action of the following:

(a) **Blood** and **lymph.**

(b) **Vessels** or spaces through which blood and lymph circulate, i.e., arteries, capillaries, veins, and lymph vessels.

(c) The **heart**, or a pumping organ, which provides the force required to move or circulate the fluids within the vessels or spaces.

SECTION 2: THE COMPOSITION AND FUNCTIONS OF BLOOD AND LYMPH

THE COMPOSITION OF BLOOD

Blood is the chief fluid that flows in the circulatory system and constitutes about 8% of the body weight in human beings. Blood consists of:

(a) **plasma**, the fluid part which forms about 55% of the total volume of the blood; and

(b) **blood corpuscles** or cells suspended in the plasma, which form the remaining 45% (Fig. 20. 1).

	PLASMA	BLOOD CORPUSCLES
BLOOD	55%	45%

PLASMA

Plasma is a clear, pale yellow fluid. It is slightly **alkaline** and provides a suitable medium for the functioning of blood corpuscles. It is a solution made up of the following chemical substances dissolved in water.

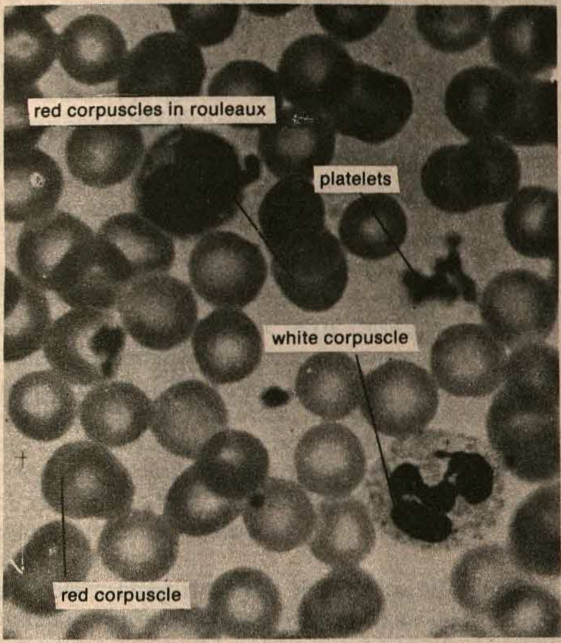


FIG. 20.1 Microphotograph of human blood magnified 200 times. (Red corpuscles sometimes cling together and are said to be in rouleaux.

(i) **Mineral salts**, i.e., chlorides, sulphates, bicarbonates, and phosphates of elements such as sodium, potassium, calcium, and magnesium.
(ii) **Dissolved food substances** such as digested proteins, carbohydrates, fats, and vitamins.
(iii) **Waste substances** such as urea, uric acid, and carbon dioxide.
(iv) **Hormones.**
(v) **Dissolved blood proteins** such as fibrinogen, albumins, and globulins.

All these substances, except blood proteins, are transported by plasma from one part of the body to another. The blood proteins, nevertheless, form an essential part of plasma.

As the blood flows past the cells, the cells shed substances into blood constantly and also remove substances from it. Plasma provides the medium through which this continual exchange takes place.

BLOOD CORPUSCLES

Plasma also contains three types of blood corpuscles or cells:

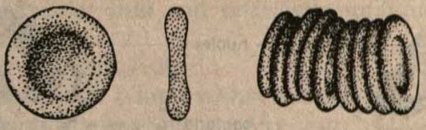


FIG. 20.2 Human red blood corpuscles: in rouleaux; front view; and side view

(i) Red blood corpuscles, also called **erythrocytes.**
(ii) White blood corpuscles, also called **leucocytes.**
(iii) Blood platelets, also called **thrombocytes.**

Let us now discuss these three types individually.

Red blood corpuscles are small biconcave, disc-like cells, each measuring about 7.5 microns in diameter and about 2 microns in thickness [Fig.20.2]. There are about 5,000,000 red blood cells in 1 mm^3 of blood in case of a man, and about 10% less in case of a woman. These cells contain an iron-rich pigment called **haemoglobin** in their cytoplasm and do not have a nucleus. They have a short span of life, and do not live beyond 120 days. Although numerous red corpuscles die every day, yet, their number remains more or less constant because they are constantly produced at the rate of about one million per second in red bone marrow, primarily in the ribs, vertebrae, sternum (breast bone), and the long bones of the arms and legs.

When oxygen is present in a fairly high concentration, haemoglobin quickly combines with it to form an unstable compound known as **oxyhaemoglobin.** This combination takes place in the lungs, from where the blood carries oxygen to the various tissues of the body. Oxyhaemoglobin is a scarlet compound and, therefore, the blood flowing from the lungs is scarlet-red in colour. In the tissues, the continuous use of oxygen results in a low concentration of this gas. Therefore, when the oxygenated blood reaches these tissues, the oxyhaemoglobin breaks down to release its oxygen to the tissues and becomes haemoglobin once again. This causes a change in the colour of blood, from scarlet-red to purplish red, which accounts for the difference in colour between **oxygenated** (with oxyhaemoglobin) and **deoxygenated** (with haemoglobin) blood.

Thus, the red blood cells, with their haemoglobin, are very efficient carriers of oxygen from the air in the lungs to the tissues of the body.

White blood corpuscles are much fewer in number than the red blood corpuscles. Only about

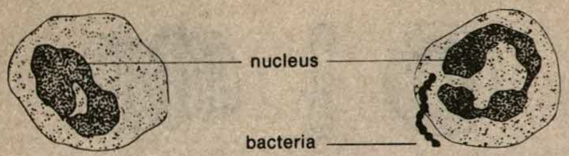


FIG. 20.3 Human white blood corpuscles, in section and while engulfing bacteria for destruction

8000 white corpuscles are present in 1 mm^3 of blood. In human blood, the proportion of red blood corpuscles to white blood corpuscles is 600 : 1. Their life span varies from 12 hours to 12 days.

White blood corpuscles are produced in the bone marrow, the lymph glands, and the spleen. Unlike red blood corpuscles, they have **nuclei** [Fig. 20. 3]. They have an irregular shape, which is ever changing because most of them are capable of moving like *Amoeba*. A majority of white blood corpuscles are of a type called **phagocytes** which can pass through most of the blood capillaries by squeezing out through intercellular spaces in the capillary walls. They collect at the site of an injury or infection to counter the effect of the infecting microbes. They destroy these microbes by following them around, engulfing, and then digesting them. They also produce **antibodies** in the plasma. (Antibodies are chemical substances which act upon the more virulent types of microbes and make it easier for the white blood corpuscles to destroy them.) The antibodies also neutralise the **toxins** or poisons produced in the blood by the microbes.

When a blood vessel gets cut and the blood flows out, the **blood platelets** disintegrate and liberate an enzyme called **thrombokinase** into the plasma. The damaged walls of the blood vessel also produce thrombokinase. In the presence of **calcium ions** (already present in the plasma), thrombokinase activates the inactive plasma protein **prothrombin** to change to the active enzyme **thrombin.** This latter enzyme changes fibrinogen, the soluble protein in the plasma, to an insoluble form known as **fibrin**. Fibrin forms a network of fibres across the cut surface, and the blood corpuscles get trapped between them to form a **clot** or **thrombus**. The corpuscles trapped in the fibrin dry, die, and harden to form a scab under which the wound can heal. This scab also prevents the entry of foreign particles. The clot formation stops excessive bleeding immediately after its formation [Fig. 20.4].

While circulating in the blood vessels of a healthy person, blood is prevented from clotting due to the presence of an enzyme called **heparin**. Heparin does not allow the inactive prothrombin to change to active thrombin.

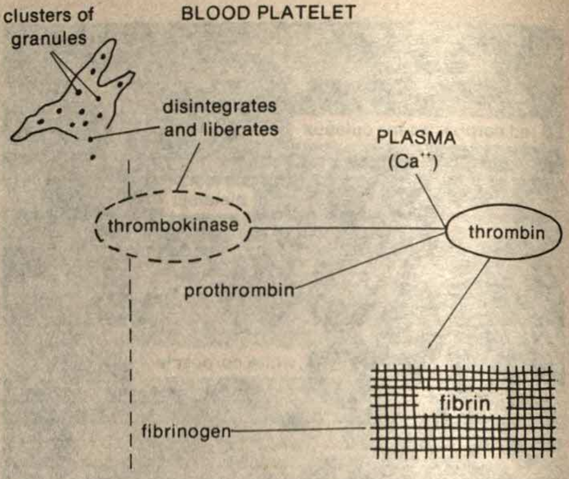


FIG. 20.4 The process of clotting of blood

THE FUNCTIONS OF BLOOD

Blood performs three kinds of functions, which are as follows.

1. Transport: Blood acts as a 'transport system in the body and ensures that every cell is supplied with food, oxygen, and other substances which it needs for efficient working. Blood also ensures the removal of waste substances of metabolism from the body. The various substances transported by blood are:

(a) **Oxygen:** carried by the haemoglobin of red blood cells from the lungs to the respiring cells.

(b) **Carbon dioxide:** carried from the respiring cells to the lungs, for ultimate removal from the body. Most of the carbon dioxide (about 80%) is carried in the plasma in the form of sodium bicarbonate and potassium bicarbonate. About 10% of the carbon dioxide is dissolved in the plasma and the remaining 10% carried by the red blood corpuscles.

(c) **Food substances:** absorbed in villi of the ileum and carried in a solution formed by the plasma to the liver and then to the metabolising cells.

(d) **Excretory products** (besides carbon dioxide): the blood plasma also transports the nitrogen-containing metabolic wastes to the skin, kidneys, and liver for excretion.

(e) **Hormones:** carried in the plasma from the endocrine glands which secrete these to the specific target organs.

(f) **Heat:** carried from the chief heat-producing tissues and organs (e.g., muscles, liver) to all regions of the body and distributed evenly around the body so that a uniform temperature is maintained throughout the body.

2. **Prevention of infection:** Foreign organisms such as bacteria enter the body through the lining of the respiratory passages, alimentary canal, and cuts in the skin, and cause infection. Many of these microbes are **pathogenic**, i.e., they can produce disease. These microbes are destroyed by the white blood corpuscles and the toxins produced by these microbes are also neutralised by antitoxins, as already explained. (See also chapter on disease and immunity.)

3. **Formation of clots:** This process prevents excessive loss of blood when blood vessels are damaged.

LYMPH AND ITS FUNCTIONS

In our body tissues, the cells are surrounded by tiny channels and spaces filled with **lymph** or tissue fluid. This fluid is formed from the blood by a process of **ultrafiltration.** At the arterial end of a blood capillary, the higher pressure of the blood forces the fluid part (of the blood) out through the thin walls of the capillary. Lymph is a pale, straw-coloured fluid which is very similar to blood except that it has no red blood corpuscles; it contains fewer blood proteins, more waste substances, and more white blood corpuscles, when compared to blood.

Lymph circulates amongst the cells and acts as a 'middle-man' between the blood and the tissue cells for the exchange of oxygen, food substances, and metabolic wastes. Excess of lymph drains into tiny thin-walled vessels called **lymph vessels**, which eventually pour their contents into the blood stream through veins at the base of the neck.

Unlike blood vessels, lymph vessels possess swellings, called **lymph nodes**, at intervals along their length. The lymph nodes produce white blood corpuscles and antibodies, which destroy harmful microbes.

Lymph vessels resemble veins in that:

(a) they carry lymph towards the heart;

(b) they have thin and relatively non-muscular walls;

(c) they contain a valve;

(d) the flow of lymph within them is steady and takes place at a low pressure; and

(e) the lymph they carry is deoxygenated.

The lymph system performs the following functions in our body:

(a) Collecting blood plasma which has diffused out from the blood capillaries, and returning it to the blood stream.

(b) Removing some of the excretory substances produced in the metabolising cells.

(c) Removing and transferring the secretions from the endocrine gland cells to the blood.

(d) Collecting digested fats from the ileum with the help of lacteals.

(e) Producing certain white blood corpuscles and antibodies to destroy microbes.

SECTION 3: THE HEART

The **heart** is a tough muscular organ which works continuously day and night, as long as one is alive. It is roughly shaped like an inverted cone and measures the size of one's closed fist. The heart is situated in the middle of the chest cavity, between the two lungs, and its apex is slightly inclined towards the left. It is enclosed in a strong membrane-like, two-layered bag called the **pericardium.** The small space between the two layers of the pericardium contains a lubricating fluid which helps the pumping movements of the heart to take place with minimum friction.

The heart is basically a pumping organ. It pumps in blood from all parts of the body and then pumps it out back to various parts of the body. The chemical composition of the blood does not change as it passes through the various chambers of the heart. This indicates that the function of the heart involves only mechanical action.

The human heart has four chambers: two lower and larger chambers, called the **right** and **left ventricles,** and two upper and smaller chambers called the **right** and **left auricles** [Fig. 20.5]. All the four chambers have strong muscular walls. The walls of the two auricles are thin while those of the two ventricles are extremely thick. The thickness corresponds to the amount of work done or the pumping action performed by the chambers. The auricles have only to force the blood into the ventricles and hence they are thin-walled. The

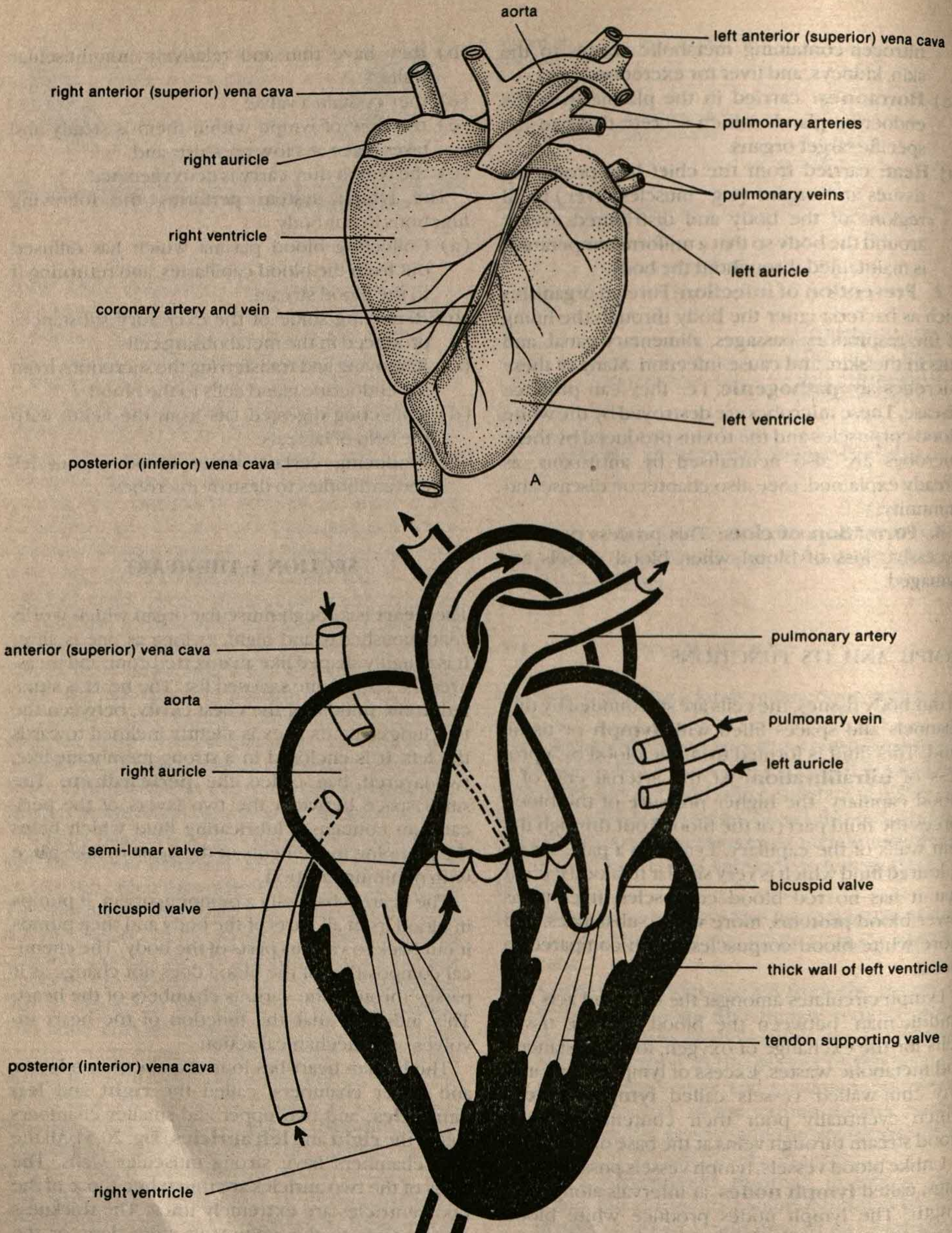


FIG. 20.5 A: The external structure of the heart B: Heart cut open vertically to show circulation of blood.

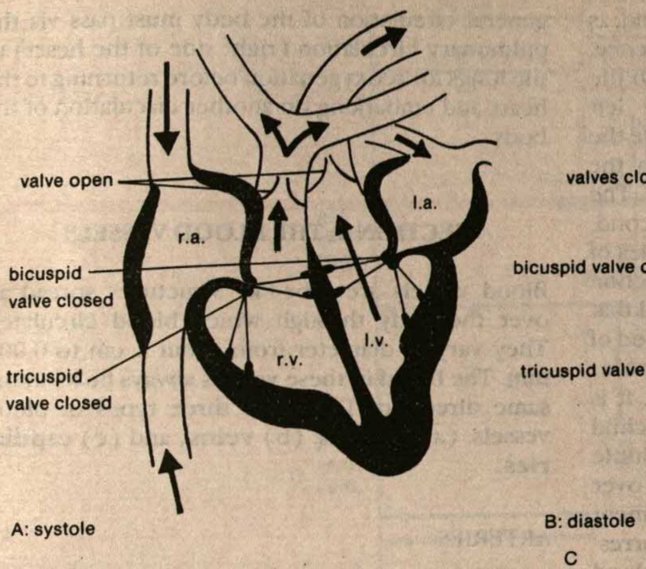


FIG. 20.5 Mammalian heart cut open to show action of valves.

walls of the right ventricle are only slightly thick because it has to pump blood only through the lungs which are close to the heart, whereas the walls of the left ventricle are much thicker because it has to pump out blood to all parts of the body.

Deoxygenated blood from all parts of the body is pumped into, or received by, the heart through two large veins:

(a) The **superior vena cava,** which carries in blood from the head, the arms, and the upper parts of the body.

(b) The **inferior vena cava,** which carries in blood from the legs and those parts of the body that lie below the heart.

From the right auricle, the blood moves into the right ventricle through an opening controlled by a valve known as the **tricuspid valve.** This valve consists of three flaps which project into the right ventricle. The free edges of these flaps are fixed to the inside wall of the right ventricle by means of strong threads called **chordae tendineae.** These threads prevent the valves from being pushed back into the auricles when the ventricle contracts and thus do not allow the blood to flow back from the right ventricle to the right auricle.

A large **pulmonary artery** carries deoxygenated blood from the right ventricle to the lungs. At the origin of the pulmonary artery, three **semi-lunar** or pocket-shaped valves are present with their openings directed away from the ventricles. When the blood goes from the right ventricle to the pulmonary artery, these valves are pushed aside to allow free passage of blood. However, these valves prevent the return flow of blood from the pulmonary artery into the right ventricle because whenever there is a lack of pressure, the three pockets of the semi-lunar valves get filled with blood and meet in the centre and block the passage. The semi-lunar valves remain flattened against the wall of the pulmonary artery if the blood flows in the right direction.

The deoxygenated and purplish-red blood carried to the lungs by the pulmonary artery gives out carbon dioxide to the air in the lungs and takes in oxygen from this air. Thus, the blood becomes oxygenated and takes on a scarlet colour.

From the two lungs, two pairs of **pulmonary veins** bring the oxygenated blood into the left auricle. The oxygenated blood moves from the left auricle to the left ventricle through an opening controlled by the **bicuspid valve.** The bicuspid valve consists of only two flaps and functions like the tricuspid valve, i.e., it prevents the flow of blood from the left ventricle to the left auricle.

A large artery called the **aorta** carries the oxygenated blood from the left ventricle to all parts of the body. The aorta also has three semi-lunar valves which, like the semi-lunar valves at the base of the pulmonary artery, allow the blood to flow in one direction only, i.e., from the ventricle to the aorta.

The two auricles contract simultaneously and, as they do so, the ventricles relax. As a consequence, the blood from the two auricles is driven into the respective ventricles. Both the right and left ventricles then contract at the same time, while the auricles relax, and the blood is driven into the pulmonary artery and the aorta, respectively. The whole heart then rests for nearly half a second, after which, the process is repeated. This series of events constitutes the **heart beat.** The contraction of auricles is known as **auricular systole** and that of ventricles as **ventricular systole.** The period of relaxation of the whole heart is known as **diastole.**

The rate of the heart beat varies with age. It is about 140 beats per minute in a newly born child and gradually reduces to about 70 beats per minute in an adult (at rest), but this rate increases to over 100 during vigorous activity or due to excitement or fever. An increased rate of the heart beat correspondingly increases the speed with which blood supplies food and oxygen to the tissues of the body so as to meet their increased demand due to a higher amount of activity.

In human beings, the heart is distinctly divided into left and right sides, dealing with oxygenated blood and deoxygenated blood, respectively. This prevents the mixing of the two types of blood. There is no connection between the left and right sides of the heart, thus producing a **double circulation** [Fig. 20.6], in which the blood returning from the general circulation of the body must pass via the pulmonary circulation (right side of the heart) to the lungs for reoxygenation before returning to the heart and embarking on another circulation of the body.

SECTION 4: THE BLOOD VESSELS

Blood vessels are tube-like structures spread all over the body through which blood circulates. They vary in diameter from about 1 cm to 0.001 mm. The blood in these vessels always flows in the same direction. There are three types of blood vessels: (a) **arteries**, (b) **veins**, and (c) **capillaries.**

ARTERIES

Arteries are the wider blood vessels which carry the blood from the heart to the different organs. Their walls are thick and elastic and can withstand the high pressure with which the blood flows through them. Arteries usually carry **oxygenated** blood, except for the pulmonary artery, which carries **deoxygenated** blood from the right ventricle to the lungs. When an artery enters an organ, it divides into thinner **arterioles,** which further divide repeatedly, becoming thinner gradually, until they form a dense network of microscopic blood vessels called **capillaries.**

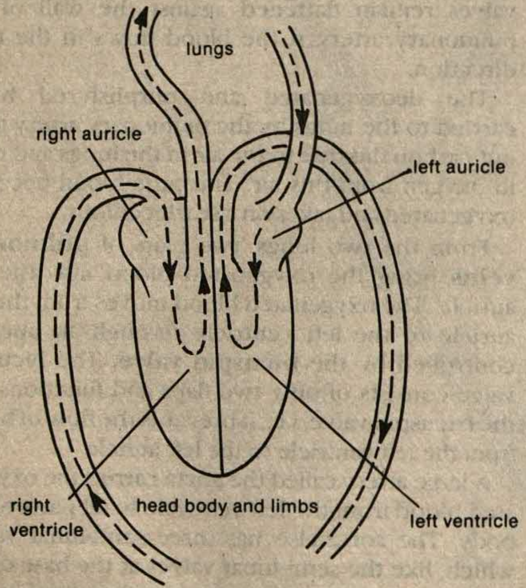


FIG. 20.6 The double circulation of a mammal

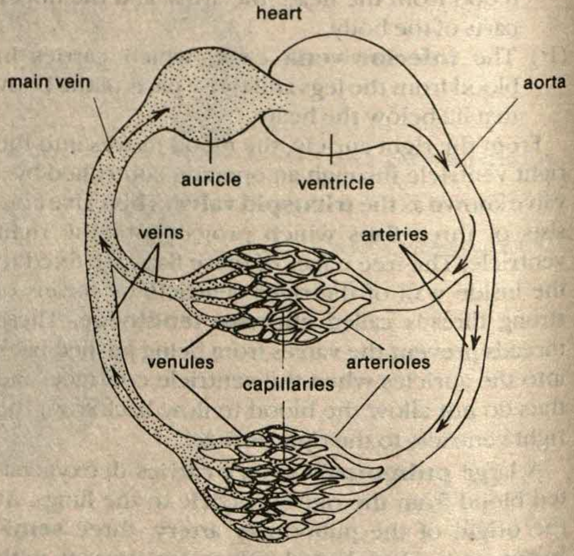


FIG. 20.7 Simple plan of circulation in vertebrate

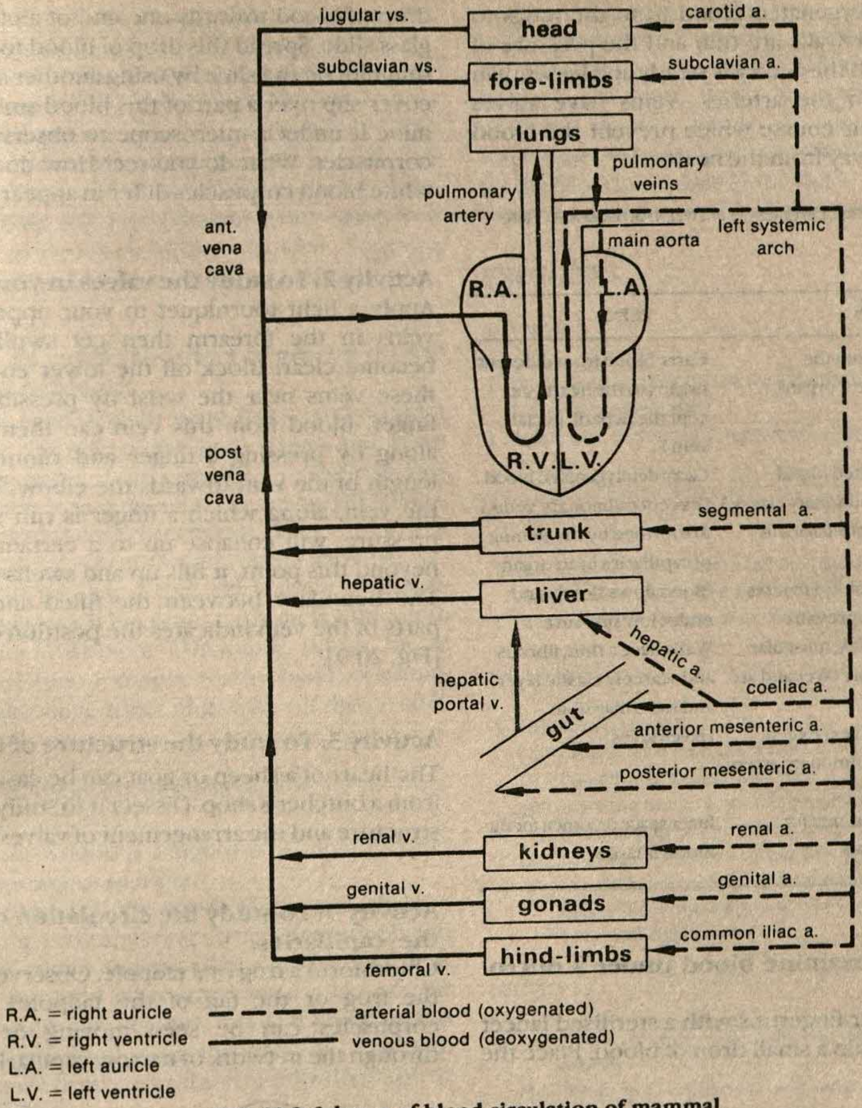


FIG. 20.8 Scheme of blood circulation of mammal

CAPILLARIES

Capillaries are extremely narrow blood vessels with exceedingly thin walls composed of a single layer of cells. These thin walls enable the exchange of materials by diffusion, between the blood and the cells of the surrounding organ through the tissue fluid. Capillaries are formed in all the organs of the body, so that each and every cell of the body lies very close to a capillary. Through these thin walls, food substances, oxygen, and hormones diffuse out from the blood into the surrounding tissue fluid for the cells and waste materials such as carbon dioxide, urea, and uric acid, diffuse from the cells into the surrounding tissue fluid and thence into the blood from the cells.

Finally, the capillaries unite to form larger vessels called **venules,** which, in turn, join together to form **veins.**

VEINS

Veins usually return the deoxygenated blood from an organ to the heart, except for pulmonary veins which bring oxygenated blood from the lungs to the heart. Their walls are thin and the pressure of the blood which they carry is steady and lesser than the pressure in the arteries. Veins have valves throughout their course which prevent the blood from flowing away from the heart.

Table 20.1 General Differences between Arteries and Veins

ARTERIES	VEINS
(1) Carry blood from the heart to different organs.	Carry blood from different organs to the heart (except the hepatic portal vein)
(2) Carry oxygenated blood (except the pulmonary artery)	Carry deoxygenated blood (except pulmonary veins)
(3) Break up into capillaries in an organ	Are formed by the joining of capillaries in an organ
(4) Blood flows rapidly (in jerks) and under high pressure	Blood flows slowly and under low pressure
(5) Walls have a thick, muscular and highly elastic layer and are not collapsible.	Walls have a thin, fibrous and scarcely elastic layer and are collapsible
(6) Do not have valves (except the aorta and pulmonary artery, near their base)	Have valves
(7) Inner space or lumen for the blood is small	Inner space or lumen for the blood is large

Activity 1: To examine blood under a microscope.
Prick one of your fingertips with a sterilised lancet or needle to obtain a small drop of blood. Place the drop of blood towards one end of a clean and dry glass slide. Spread this drop of blood to form a very thin film on the slide by using another slide. Place a cover-slip over a part of this blood smear and examine it under a microscope to observe the blood corpuscles. What do you see? How do the red and white blood corpuscles differ in appearance?

Activity 2: To study the valves in your veins.
Apply a light tourniquet to your upper arm. The veins in the forearm then get swollen up and become clear. Block off the lower end of one of these veins near the wrist by pressing it with a finger. Blood from this vein can then be pushed along by pressing a finger and running it along length of the vein towards the elbow. That part of the vein, along which a finger is run with a light pressure, will collapse up to a certain point, and beyond this point, it fills up and swells once more. The boundary between the filled and collapsed parts of the vein indicates the position of the valve [Fig. 20.9].

Activity 3: To study the structure of the heart.
The heart of a sheep or goat can be easily obtained from a butcher's shop. Dissect it to study its internal structure and the arrangement of valves in it.

Activity 4: To study the circulation of blood in the capillaries.
Chloroform a frog or a tadpole. Observe the web of the frog or the tail of the tadpole. The blood corpuscles can be seen moving or streaming through the network of narrow capillaries.

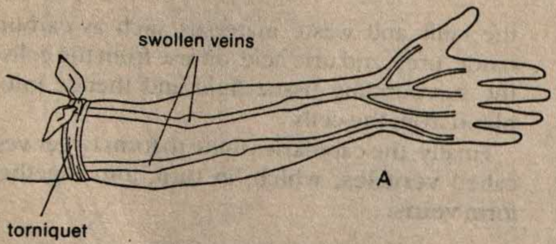


FIG. 20.9A Human arm with tourniquet

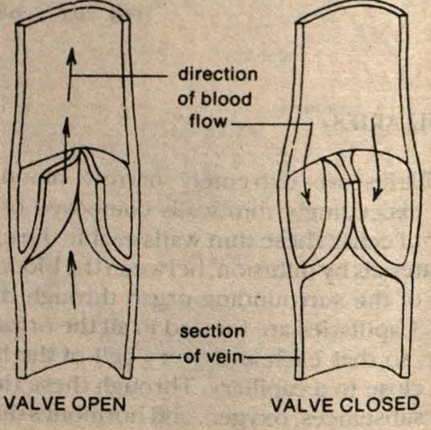


FIG. 20.9B Achiad valves in veins

Activity 5: To study the pulse rate and the effect of exercise on it.
You can measure your own pulse by placing your right hand fingers on your left wrist. The movement of blood through the arteries can be felt as jerks. Count your pulse rate or the number of beats per second while you are at rest. Now, run around the school building and count the pulse rate again. You will find it to be much higher this time. Find out how long it takes to return to its original rate.

Activity 6: To study the effect of gravity on the circulation of blood.
Allow your right arm to hang freely and straight down along the side of the body. Open and close the fist repeatedly. It is possible to continue this movement for 3 to 4 minutes, or up to 500 times, without feeling much discomfort. After a period of rest, raise the same arm and repeat the above movement. It will be found that after about a minute (or 100 closures), it becomes extremely difficult to perform this movement. Obviously, this is due to the reduced blood supply to the hand, resulting from the retarding effect of gravity on the circulation of blood.

FIRST AID IN CASE OF BLEEDING

A deep cut or wound is dangerous because it could result in a great loss of blood.

The simplest and the most effective method to stop bleeding is by applying direct pressure on and around the cut or wound with a gauze pad. It is important to apply constant pressure. Do not lift the gauze every few seconds to see if bleeding has stopped. If no blood soaks through, you can then bind the gauze firmly over the wound with a tape or strips of cloth.

Another method of stopping bleeding is the application of a **tourniquet.** This is a tight band that is placed around an arm or leg to control heavy bleeding. This is how it is made: Wind a flat band **twice** around the leg or arm, just above the wound. A necktie, stocking, or large handkerchief may be used for this purpose. Tie a single knot, then hold a small stick on top of the knot, and tie two more knots. Gently twist the stick, until the band is tight enough to stop the flow of blood. Do not twist beyond this point. Leave the tourniquet in place until the doctor comes. Be sure to loosen the tourniquet every ten minutes for a few seconds to let the blood circulate in the limb.

EXERCISES

SECTION 1

1. What are the functions of the circulatory system and why is this system important?
2. Name the parts and constituents of the human circulatory system.

SECTION 2

3. Name the components of human blood and state the composition and functions of each of them.
4. What changes take place in the blood during its clotting?

SECTION 3

5. (a) What is lymph?
   (b) How does lymph differ from blood plasma?
   (c) State the functions of lymph.
   (d) State the functions of the lymphatic system.
6. (a) Draw and label a neat diagram of the human heart.
   (b) State the functions of the following parts of the heart: (i) tricuspid valve; (ii) bicuspid valve; (iii) pulmonary artery; (iv) coronary artery; (v) pulmonary veins; and (vi) semi-lunar valves.

SECTION 4

7. (a) How can arteries and veins be distinguished from each other?
   (b) What are capillaries and how are their functions (i) similar to and (ii) different from, the functions of arteries and veins?
8. Trace the path of (a) blood from your brain to the left ventricle of the heart and (b) a molecule of glucose from the ileum to the cardiac muscles.
9. (a) What are 'heart beat' and 'pulse rate'?
   (b) How are they affected by (i) strenuous exercise and (ii) high fever?

CHAPTER 21

Respiration and the Organs of Breathing

SECTION 1: IMPORTANCE OF RESPIRATION

Respiration is one of the most important characteristics of all forms of life. All living organisms—plants as well as animals—must respire in order to obtain the energy needed for the synthesis of ATP—the immediate source of energy for various activities constantly taking place in their living cells (e.g., metabolism, growth, and reproduction).

In animals, energy is also required for specialised functions such as the movements of the body, working of the muscles, and conduction of nerve impulses. Even when at rest, the cells of an organism need energy because various physiological processes continue to take place. This process which makes energy available to the cell, and thus to the rest of the body, is called **respiration**.

Respiration is essentially a chemical process in which simple food substances, chiefly glucose, are **oxidised** to release energy. Such oxidation occurs in all living cells; specifically, in the **mitochondria** of living cells. Respiration can be chemically represented by the following simple equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} \xrightarrow[\text{living cells}]{\text{in all}} \underset{\substack{\text{carbon}\\\text{dioxide}}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy (2830 kJ)}$$

In living organisms, respiration is of two types: **breathing** (external respiration) and **tissue respiration** (internal respiration).

EXTERNAL RESPIRATION OR BREATHING

This activity includes the action of special organs and the methods by which oxygen (required for respiration in the cells) is taken into the body, and carbon dioxide (formed as a waste product during respiration in the cells) is given out. Thus, breathing involves only an exchange of gases, i.e., oxygen and carbon dioxide, and the concerned organs. For example, in human beings, the breathing organs comprise the two lungs and, in plants, they consist of, mainly, the green leaves.

INTERNAL RESPIRATION OR TISSUE RESPIRATION

This process occurs inside living cells only and involves a complicated series of enzyme-controlled chemical reactions in which energy is released at every stage for ATP synthesis in the cells, as already discussed in an earlier chapter. This aspect of respiration is fundamentally the same in **all forms of life** and in **all cells** of the body.

METHODS OF BREATHING

For taking in oxygen, different animals have differ-

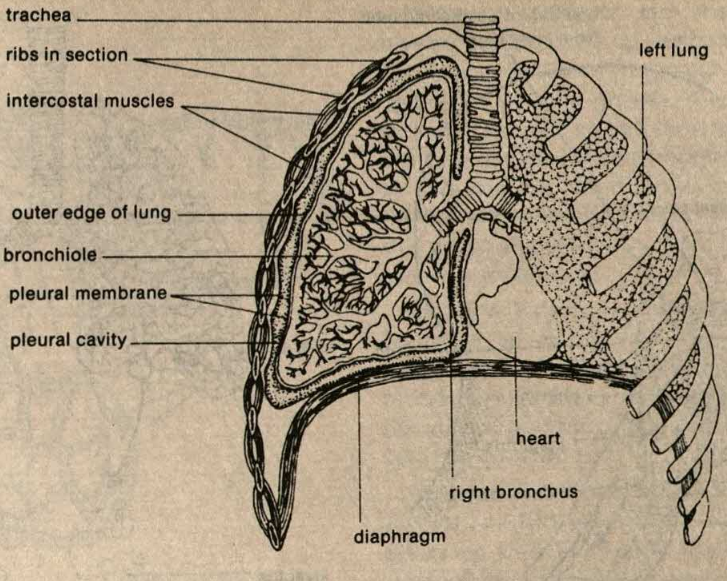


FIG. 21.1 Longitudinal section through human thorax

ent methods of breathing. In unicellular and some other simple animals which have no specialised organs for oxygen-carbon dioxide exchange, such an exchange is carried out directly (and adequately) between the organism and its environment by diffusion. However, most of the complex and multicellular animals do have **breathing organs** through which the exchange of gases takes place, again by diffusion.

Based on the type of respiratory surfaces or organs used for the oxygen-carbon dioxide exchange, we have the following groups of animals:

(i) Skin breathers or surface breathers, like frogs and earthworms.
(ii) Air tube breathers, like insects.
(iii) Gill breathers, like fishes.
(iv) Lung breathers, like reptiles, birds, and mammals.

SECTION 2: ORGANS OF BREATHING IN HUMAN BEINGS

The organs concerned with oxygen-carbon dioxide exchange in a human being are a pair of lungs. The movement of air to and from the lungs takes place through the following associated structures: (a) nostrils; (b) nasal cavities; (c) pharynx; (d) trachea; (e) bronchi; (f) bronchioles (in the lungs); and (g) air sacs (in the lungs).

The **lungs** are spongy, elastic organs situated in the **thoracic** or **chest cavity** and are enclosed within two **pleural membranes.** The space between the outer and inner pleural membranes is called the **pleural cavity**, which contains a lymph-like fluid that cushions the lungs during breathing movements. The right lung has three lobes, the left lung two, and the heart lies between the two lungs [Fig. 21.1]. The chest cavity, which is above the diaphragm, is a hollow, barrel-shaped space with the vertebral column at the back, the sternum (breastbone) in front, and the ribs on the sides. The **diaphragm** is a thin muscular sheet, forming the floor of the chest cavity. When at rest, the diaphragm is dome-shaped (or arched upwards), projecting into the chest cavity.

As the atmospheric air passes through the two **nasal cavities**, it is warmed, moistened, and filtered by the **mucus** and hair present in these cavities so as to get rid of dust and other foreign particles. From the nasal cavities, the air now enters the pharynx. The **glottis** [Fig. 21.2] is an aperture at the base of the pharynx through which the air enters the trachea. The entry of food and water into the glottis is prevented by a flap-like lid of cartilage, called the **epiglottis,** which closes over it at the time of swallowing. The glottis is normally open to allow air to pass freely into the uppermost part of the trachea, called **larynx** or **sound box.** The

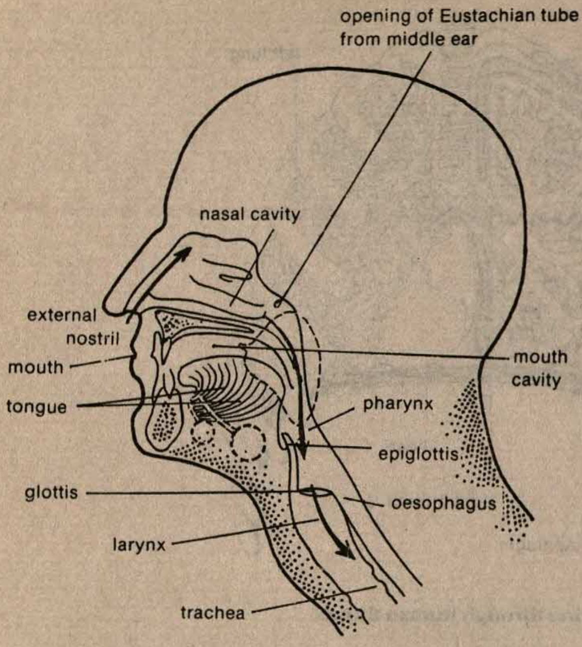


FIG. 21.2 Longitudinal section through human head showing pathway of inhaled air

larynx is surrounded by a complex of cartilages and contains the **vocal cords** stretched across within it. Sound is produced by the vibrations caused by the air when it passes out through the larynx.

The **trachea** (or wind pipe) is a tube-like structure about 10 cm to 15 cm long and about 2 cm in diameter. It lies in front of the food pipe and extends from the larynx, through the neck, into the chest cavity. In the chest cavity it branches into the **right bronchus** and the **left bronchus** (plural **bronchi**) which enter the right and left lungs, respectively. Immediately on entering the lungs, each bronchus begins to branch into progressively smaller tubes, called **bronchioles,** finally terminating in a cluster of microscopic **air sacs** called the **alveoli**. These air sacs are the functional units of the lungs, i.e., the centres where the oxygen-carbon dioxide exchange takes place between the air and the blood. There are nearly one billion air sacs in the two lungs of each human being.

The trachea, the two bronchi, and the larger bronchioles are supported by C-shaped, incomplete rings of cartilage which prevent these structures from collapsing and maintain an open passage for the air to pass at all periods of time. The rings of cartilage disappear as the branches of the bronchioles become thinner [Fig. 21.3].

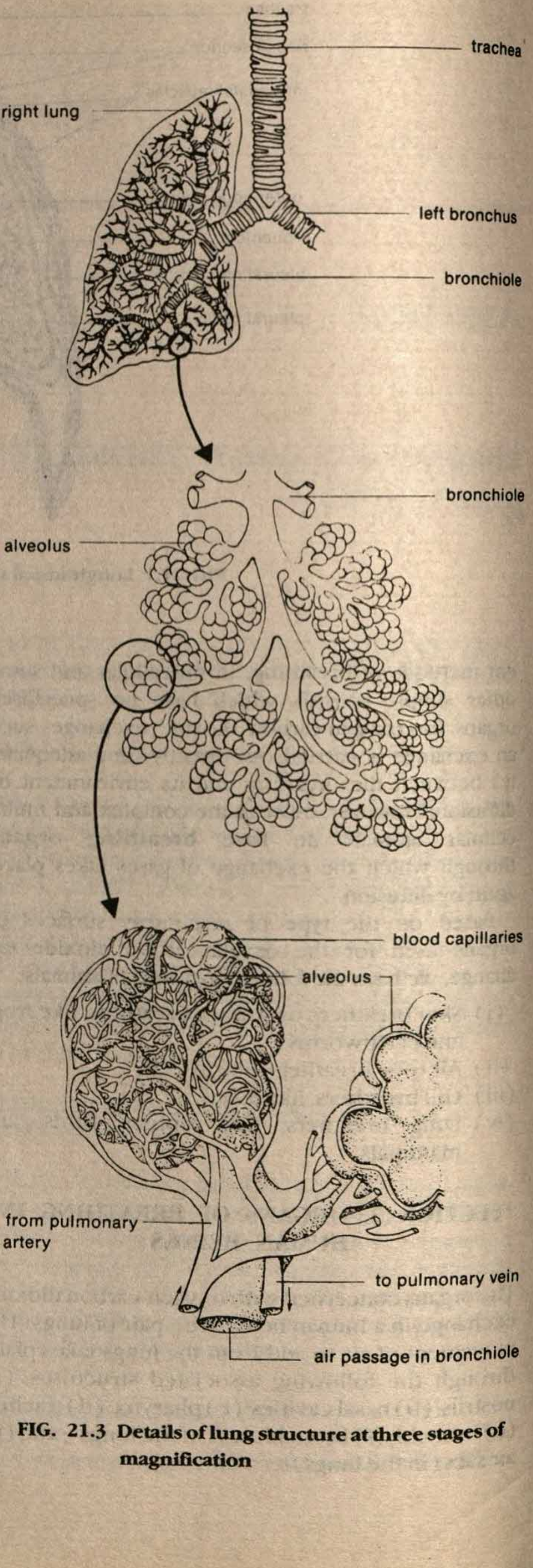


FIG. 21.3 Details of lung structure at three stages of magnification

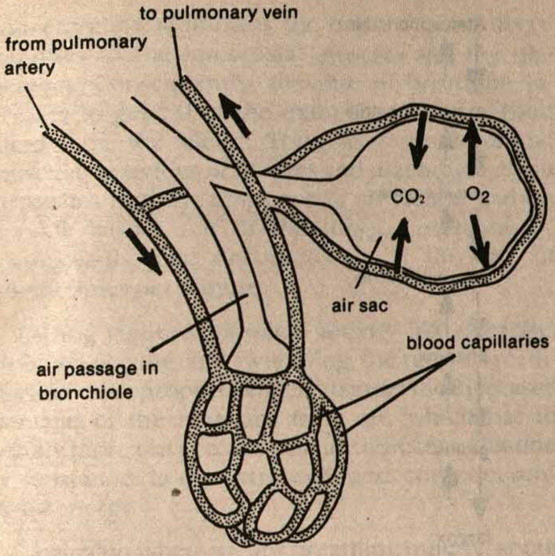


FIG. 21.4 **Gaseous exchange in the alveolus**

The air sacs possess thin, elastic walls consisting of only a single layer of cells, and are surrounded by a dense network of blood capillaries. These capillaries are formed by the repeated branching out of the two pulmonary arteries which bring deoxygenated blood, i.e., blood richer in carbon dioxide, from the right ventricle of the heart to the lungs.

Internally, each air sac has a thin lining of **mucus** which keeps its inner surface moist. Since the concentration of oxygen in blood is lower than that of the air in the air sacs, the oxygen from the air sacs dissolves in the thin mucous lining and further diffuses into the blood through the thin walls of the air sacs and the blood capillaries [Fig. 21.4]. Thus, the blood becomes richer in oxygen and transports this gas to all parts of the body with the help of red blood corpuscles.

The concentration of carbon dioxide in the air contained in the air sac is lower than that in the blood and, hence, carbon dioxide diffuses out of the blood through the capillary wall and the thin wall of the air sac, into the thin lining of mucus and thence into the alveolar air [Fig. 21.5].

The capillaries (formed by the repeated branching out of the pulmonary arteries) after having given up carbon dioxide from the blood flowing through them to the air sacs and having taken in oxygen from them, reunite to finally form pulmonary veins, which return the oxygenated blood to the left auricle of the heart.

SECTION 3: MECHANISM OF BREATHING

The process of breathing includes the taking in of fresh air (rich in oxygen) into the lungs, called breathing in or **inhalation** or **inspiration**, and the

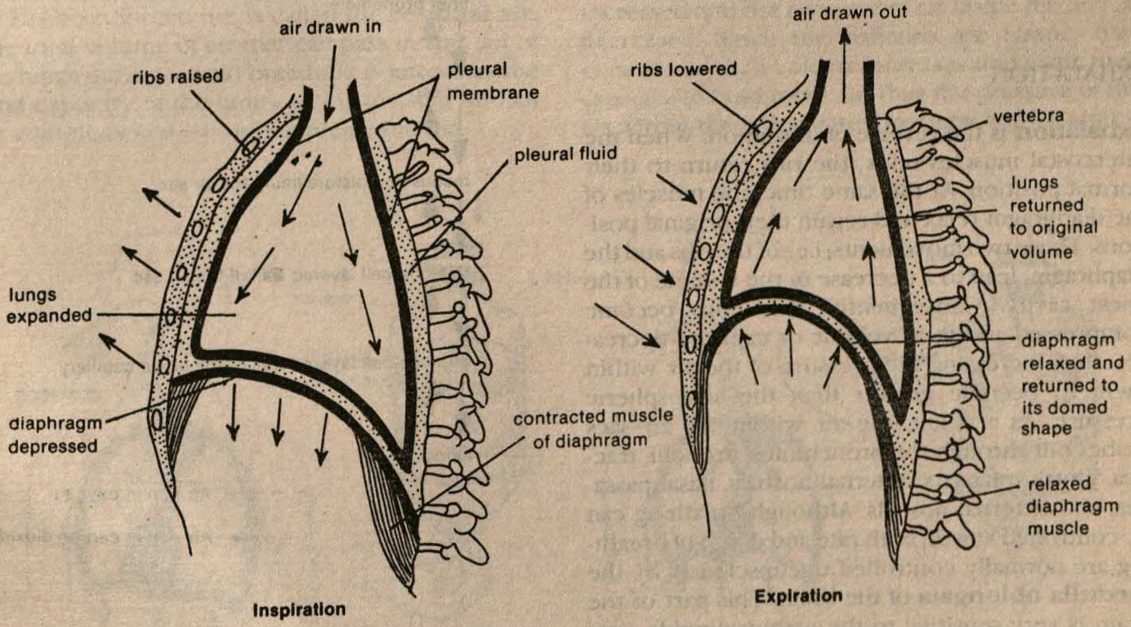


FIG. 21.5 **Mechanism of breathing**

giving out of air (rich in carbon dioxide) from within the lungs, called breathing out or **exhalation** or **expiration**. Inhalation and exhalation [Fig. 21.5] take place at the rate of 15–20 times per minute in an adult when the person is at rest. Both inhalation and exhalation depend upon the muscular movements of the diaphragm and the **intercostal muscles**, which are arranged diagonally between the ribs. When relaxed, the ribs slope downwards and inwards. As already stated, the diaphragm is arched or dome-shaped when its muscles are relaxed, i.e., when it is at rest.

INHALATION

When the intercostal muscles contract, the ribs are made to swing upwards and outwards. Simultaneously, the muscles of the diaphragm contract, flattening it. Both these movements result in an increase in the volume of the chest cavity. Since the lungs are elastic, they expand to occupy this increased volume. Due to an increase in the volume of the lungs, the pressure of the air inside them is reduced and becomes lesser than that of the atmospheric air. To equalise the pressure, therefore, the outside air rushes into the air sacs of the lungs through the external nostrils, nasal passages, internal nostrils, pharynx, glottis, trachea, bronchi, and bronchioles. This entire process is known as **inhalation.**

EXHALATION

Exhalation is the reverse of inhalation. When the intercostal muscles relax, the ribs return to their normal position. At the same time, the muscles of the diaphragm relax and regain their original positions. These two movements, i.e., of the ribs and the diaphragm, lead to a decrease in the volume of the chest cavity. Consequently, the lungs become compressed and their volume or capacity decreases, thus increasing the pressure of the air within them to become greater than the atmospheric pressure. As a result, the air within the air sacs rushes out through the bronchioles, bronchi, trachea, glottis, pharynx, internal nostrils, nasal passages, and external nostrils. Although breathing can be controlled at will, both rate and depth of breathing are normally controlled unconsciously by the **medulla oblongata** of the brain. This part of the brain is very sensitive to the carbon dioxide concentration of the blood that it receives. A rise in this

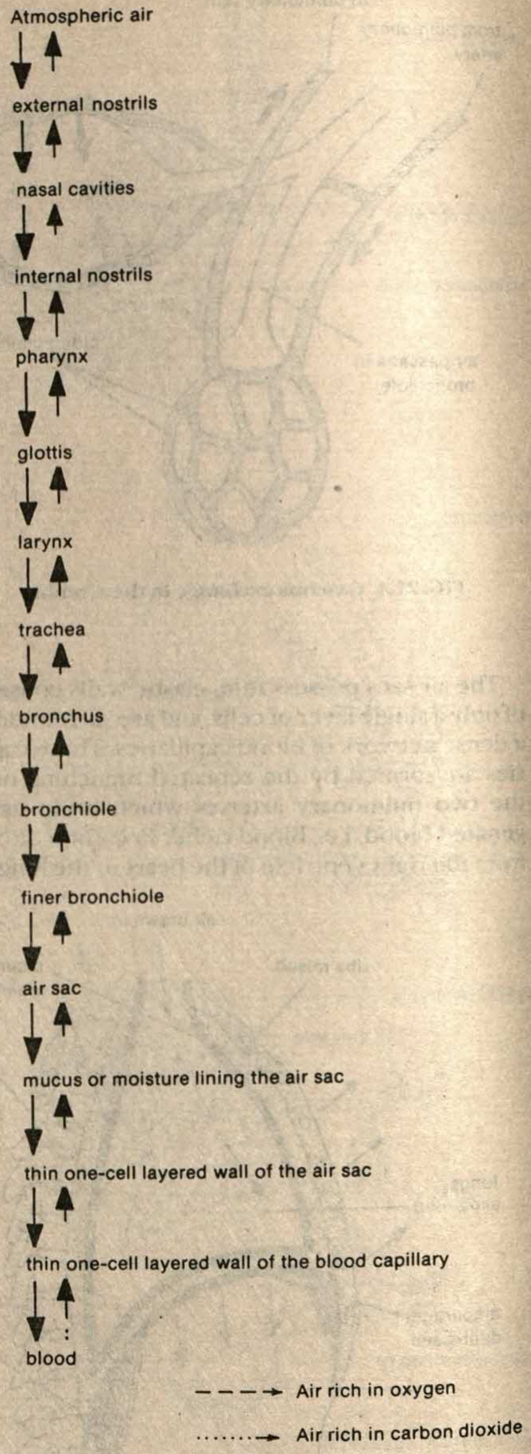


CHART OF THE MOVEMENT OF AIR AND THE EXCHANGE OF GASES DURING BREATHING

concentration stimulates the brain to send nerve impulses to the intercostal muscles and the diaphragm. Consequently, the rate of breathing increases to get rid of the extra amount of carbon dioxide in the blood. Thus, as a result of the muscular activities of the ribs and diaphragm, fresh air rushes into the lungs, while air rich in carbon dioxide rushes out of the lungs, continuously, involuntarily, and unconsciously at the rate of 15–20 times per minute.

During vigorous physical activity like exercise, running, playing, and swimming, the rate of breathing increases proportionately to meet the increased demand of the body for fresh air, which has to supply more oxygen and provide quicker oxidation of substances in the living cells and, consequently, more energy.

Normally, when we are breathing quietly, about 500 cm^3 of fresh air is taken into the lungs and, after a pause of about 2 seconds, stale air is breathed out. The air that passes in and out of the lungs during each breath is called **tidal air**. By making an effort, another 1500 cm^3 of air can be taken in and this is called **complemental air.** Additional air may be forced out of the lungs by a great effort—up to about 1500 cm^3—and this is called **supplemental air.** However, in spite of the greatest effort, all the air cannot be driven out of the lungs, and that air which remains in the lungs after the supplemental air has been forced out is called the **residual air.** The total volume of air that can pass in and out of the lungs during forced breathing is known as the **vital capacity** of the lungs, and is the sum of tidal air, complemental air, and supplemental air.

TABLE 21.1 COMPOSITION OF INHALED AIR AND EXHALED AIR

ENTITY	INHALED AIR	EXHALED AIR
Oxygen	21%	16%
Carbon dioxide	0.04%	4%
Nitrogen	78%	78%
Water vapour	Variable	Saturated
Temperature	Variable	34°C

Activity 1: To construct a working model of the human lungs and to demonstrate the action of the diaphragm.

At each of the two ends of a Y-tube, tie a balloon with a thread. Now, pass the third arm of the Y-tube through a hole in a cork fitted into the mouth of a bell-jar, as shown in the figure [Fig. 21.6]. Make the connections air-tight with molten wax and tie a sheet of rubber firmly across the bottom of the bell-jar. In this model the breathing organs are represented as follows:

LUNGS	BALLOONS
Bronchi and trachea	Y-tube
Chest cavity	Bell-jar cavity
Diaphragm	Rubber sheet
Nostrils	Openings of the Y-tube

At the beginning of the experiment, the balloons should be deflated. By pulling the rubber sheet downwards, the volume of the bell-jar cavity can be increased and the pressure of air inside the bell-jar decreased. Since the balloons are elastic, they expand and their volume increases along with their capacity to hold more air; thus the pressure of the air within them decreases. Instantaneously, atmos-

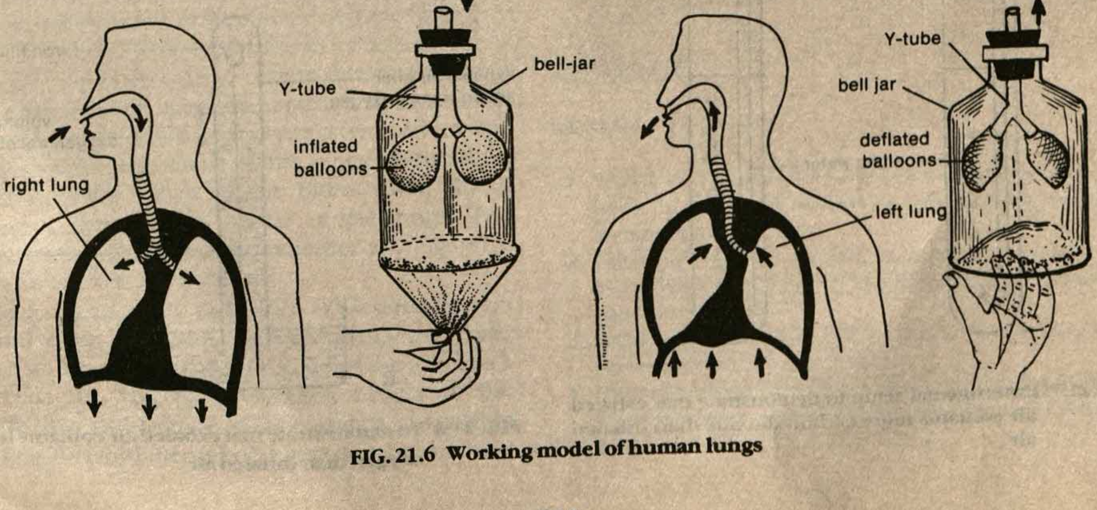


FIG. 21.6 Working model of human lungs

pheric air, which is at a higher pressure than the pressure of the air inside the balloons, rushes into the balloons through the Y-tube, to inflate them.

On releasing the stretched rubber sheet, it regains its normal flattened shape. The volume of the bell-jar cavity then decreases, the balloons get compressed, the pressure of the air inside them increases, and so the air rushes out of the balloons and they become deflated once again.

Activity 2: To demonstrate that exhaled air contains more carbon dioxide than inhaled air.

The apparatus should be set up as shown in the figure [Fig.21.7]. Place fresh lime water in each test tube. Place your mouth at X and breathe in deeply. The arrangement of the glass tubes is such that, on **inhaling**, air bubbles through the lime water in test tube A and enters your lungs, while, on **exhaling**, air leaves your lungs and bubbles through the lime water in test tube B. The samples of lime water in test tubes A and B, therefore, test the inhaled and exhaled air, respectively. What happens to the lime water in the two test tubes? What is your conclusion regarding exhaled air, from your observation of test tube B?

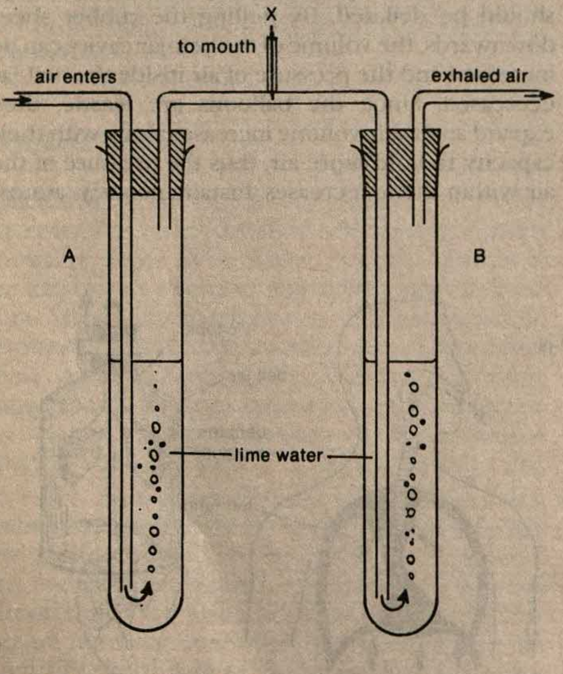


FIG. 21.7 Experimental setup to demonstrate that exhaled air contains more carbon dioxide than inhaled air

Activity 3: To demonstrate that exhaled air contains less oxygen than inhaled air.

Fill a graduated cylinder having a capacity of 20 ml with water and invert it over a glass trough containing water [Fig. 21.8]. Using a bicycle pump, bubble air into the cylinder by the downward displacement of water. Continue pumping until the water level in the cylinder and the glass trough become equal. Wrap 10 g of wet iron filings in a piece of muslin cloth and tie this package to one end of a taut copper wire. Using the wire push the package into the air trapped in the cylinder, taking care to keep the cylinder immersed in water during the entire period.

Set up an identical apparatus, and, in this case, fill the cylinder with air exhaled from your lungs.

Leave the two sets undisturbed for two days. If you look at the two apparatuses after this period, you will observe that the level of water in the cylinder containing air from the bicycle pump (atmospheric air) has risen much more than that in the cylinder containing air from your lungs (exhaled

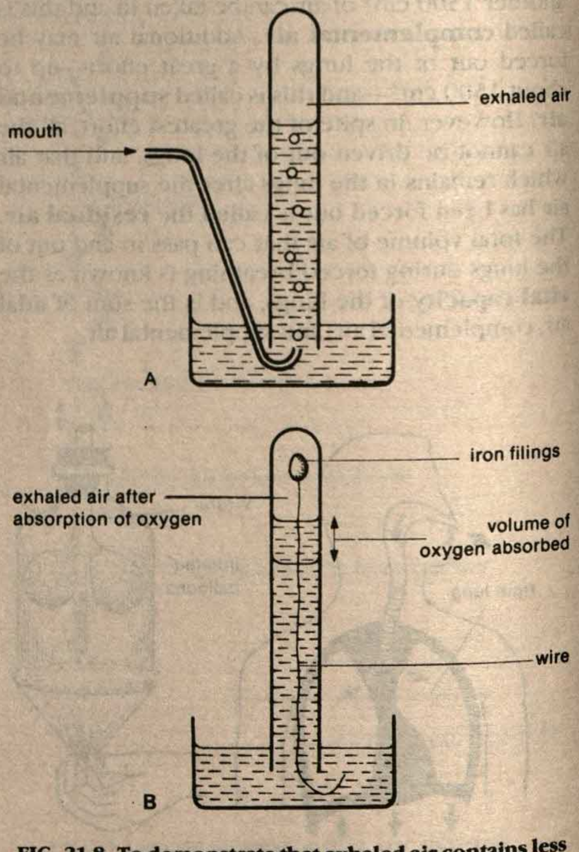

exhaled air
mouth
A
iron filings
exhaled air after absorption of oxygen
volume of oxygen absorbed
wire
B

FIG. 21.8 To demonstrate that exhaled air contains less oxygen than inhaled air

air). Why does this happen? Why do the iron filings rust? Does exhaled air contain any detectable proportion of oxygen? How do your observations show that exhaled air contains less oxygen than inhaled air? Compare your own observations and results with those now tabulated.

OBSERVATION	INHALED AIR	EXHALED AIR
Original volume of the trapped air	175 cm^3	175 cm^3
Air left in the cylinder after rusting	140 cm^3	148 cm^3
Volume of oxygen used in rusting	35 cm^3	27 cm^3
Percentage volume of oxygen	20%	15%

DANGERS OF SMOKING AND ARTIFICIAL RESPIRATION

DANGERS OF SMOKING

In recent years, scientific studies have provided evidence to show that cigarette smoking *is* injurious to health. Smoking plays a definite part in lowering a person's resistance to disease. In fact, the life span of heavy smokers could be reduced by five to ten years compared with that of non-smokers. In most cases, the affliction arises as a result of heart ailment, or damage to blood vessels, or cancer of the lungs.

Tobacco smoke contains eighteen different poisons. Among these are **tar**, a cancer-producing (carcinogenic) substance, **nicotine**, **carbon monoxide**, and **ammonia**. These harmful substances are transferred to the bronchial tubes and the lungs by the smoke, and then deposited on the mucous membranes lining these tubes, where they cause irritation. Extracts of these substances have been used by scientists to produce cancer in mice and other animals used for experimentation. Why take such poisons into your own system and run the risk of developing cancer of the lungs? Naturally, a question arises: what about filters? Will filters protect a person from cancer of the lungs? The answer is NO. It is doubtful whether any cigarette filter can ever be entirely safe.

Pipes, cigars, and *bidis* are undoubtedly less harmful than cigarettes, but not altogether safe. Even if no smoke is inhaled (e.g., chewing tobacco), one runs the risk of developing cancer of the mouth, lips, and tongue. Hence, the most sensible course is to avoid the use of tobacco in any form.

ARTIFICIAL RESPIRATION

When someone stops breathing, his very survival depends on providing artificial respiration without any delay. Artificial respiration should be continued without interruption until medical help arrives or the individual has begun to breathe again.

Artificial respiration often involves matters of life or death, especially in cases of drowning, electrocution, suffocation, strangulation (choking), carbon monoxide inhalation, and an overdose of sleeping pills.

Mouth-to-mouth breathing: This is a technique of artificial respiration by which the rescuer's breath goes directly into the victim's lungs. It is the easiest, most practical, and most efficient method.

Mouth-to-mouth breathing is carried out as follows: Place the victim on his back and tilt his head back, bringing the chin forward and up. Pull the tongue forward, grasping it between the thumb and forefinger. Hold the victim's nose firmly closed and blow gently into his mouth to inflate his lungs. Remove your mouth and listen for the outward rush of air. If there is no return of air, check for any obstruction in the mouth with your fingers. For an adult, blow at a rate of about 12 breaths per minute and for a child at about 20 breaths per minute. If the heart has stopped beating, continue mouth-to-mouth breathing, while someone else gives a cardiac massage by pressing firmly with the base of the hand over the middle of the breastbone about 60 times a minute. Be sure to lift the hand off after each application of pressure.

EXERCISES

SECTION 1

1. What is respiration? Write a simple chemical equation, in words as well as in symbols, to indicate what happens during respiration.
2. Distinguish between internal and external respiration in human beings. List the breathing organs and the respiratory organs in your body.
3. Tabulate the similarities and the differences in respiration between human beings and plants.
4. List the four types into which animals are classified according to their mode of breathing. Give three examples of each type.

SECTIONS 2 and 3

5. Name all the structures involved in the mechanism of breathing in human beings.
6. Describe the processes of (a) breathing in and (b) breathing out, in human beings.
7. With the aid of a labelled diagram explain how gases are exchanged between the blood and the air in an air sac.
8. How will you conclusively demonstrate that exhaled air contains more carbon dioxide than inhaled air?
9. Why is breathing absolutely essential for our survival?
10. State the functions and importance of the following structures in the process of breathing: (i) nasal cavities; (ii) mucus and hair in the nasal cavities; (iii) epiglottis; (iv) film of mucus on the inner surface of an air sac; and (v) diaphragm.
11. 'Smoking is injurious to health Prove this statement by giving relevant arguments.
12. Describe briefly what you understand by the term 'artificial respiration'.

CHAPTER 22

Excretion and Excretory Organs in Human Beings

SECTION 1: IMPORTANCE OF EXCRETION

Numerous chemical reactions are constantly taking place in living cells, and the sum total of all these reactions is known as **metabolism**. During cell metabolism, various end products are formed. Some of these end products are useful to the cell, whereas others are harmful wastes, and may affect the normal functioning of the cell. If these harmful wastes were allowed to collect in the cells, they would become dangerous, since their accumulation would lead to malfunctioning of the cells and, consequently, of the body as a whole. Continuous malfunctioning may even cause death in a matter of days or weeks. Hence, these wastes must be removed from the body and the process of their removal is known as **excretion**. Thus, excretion is the process by which an organism throws out from its body all the waste products and harmful chemical substances (metabolic wastes) formed during the various chemical reactions that are constantly taking place in its living cells.

EXCRETORY PRODUCTS

The chief wastes and harmful chemical substances (the excretory wastes) produced in the human body are:

(i) **carbon dioxide** and **water**, formed by the breakdown of simple carbohydrates and fats during respiration;
(ii) **nitrogenous wastes**, e.g., ammonia, urea, and uric acid, formed during the breakdown of proteins in the cells; and
(iii) **bile pigments**, formed during the breakdown of haemoglobin of the dead red blood corpuscles.

EXCRETORY ORGANS

The principal excretory organs in the human body and the main products they excrete are:

(i) **the kidneys**, which excrete nitrogenous wastes such as urea and uric acid, and also excess of water and inorganic salts;
(ii) **the lungs**, which excrete carbon dioxide and water;
(iii) **the sweat glands** in the skin, which excrete sweat, a solution of materials such as urea, uric acid, inorganic salts, and water; and
(iv) **the liver**, which excretes bile pigments formed during the breakdown of haemoglobin of the red blood corpuscles.

SECTION 2: THE KIDNEYS

THE STRUCTURE AND FUNCTIONING OF KIDNEYS

In the human body, there are two kidneys situated close to the back of the abdominal cavity, one on

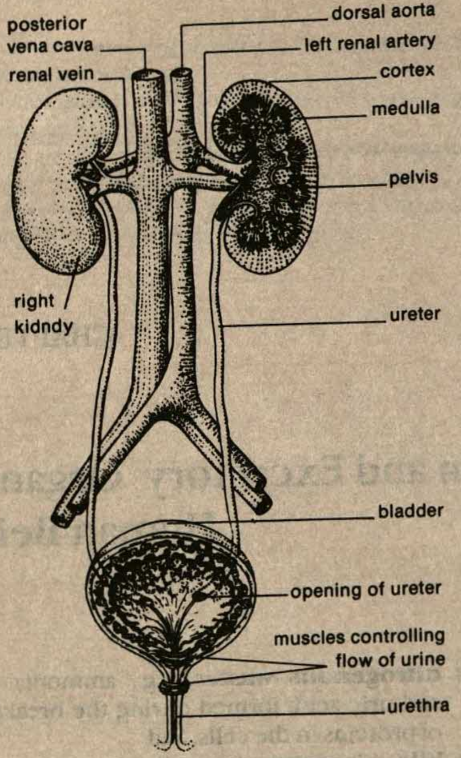


FIG. 22.1 Human kidneys and associated structures

each side of the vertebral column. The right kidney lies slightly lower than the left one. Each kidney is a bean-shaped, reddish-brown organ, and is about 12 cm long, 6 cm broad, 3 cm thick, and weighs about 150 g. The inner concave side of a kidney is called the **hilum**. The following structures enter or leave the kidney at the hilum [Fig. 22.1]:

(i) **The renal artery**, which branches off from the aorta and enters each kidney to supply it with blood rich in dissolved food substances, excess of water, and oxygen. It also brings in the harmful chemical substances such as urea and uric acid, which the kidney has to excrete.

(ii) **The ureter**, which leaves each kidney and carries urine from the kidney to the urinary bladder.

(iii) **The renal vein**, which leaves each kidney to join the inferior vena cava and carries away carbon dioxide and other chemical substances formed in the kidney.

In addition, each kidney is supplied with nerves and is enclosed in a transparent membrane called the **capsule**.

The **renal artery** further divides into **arterioles** and **capillaries** within each kidney. Dissolved food substances, oxygen, excess of water, and harmful chemical substances diffuse out of the blood carried by the capillaries of the renal arteries into the tissues of the kidney. The capillaries join to form numerous small veins which finally unite to form a **renal vein** in each kidney. The renal vein carries away the filtered blood, containing carbon dioxide and some salts, from the kidneys. Dissolved food substances and oxygen are used up for the working of the kidneys, while harmful chemical substances and excess of water are carried away from the kidneys as **urine** by the ureters.

The urine formed in the kidneys is conveyed by the ureters to an elastic and thin muscular bag known as the **urinary bladder**. The urine is temporarily stored in the bladder and later discharged to the outside by means of a duct called the **urethra**. The urethra opens out at the tip of the penis in the male and at the vulva in the female.

When a longitudinal section of a kidney is examined, two regions can be distinctly seen [Fig. 22.2]: the dark and brownish outer region, called the **cortex**, and the lighter and reddish inner region, called the **medulla**. Towards the concave side of each kidney, after the cortex and the medulla, is a cavity called the **pelvis**.

Each kidney is a mass of numerous blood vessels: **arterioles, capillaries,** and **venules** and thin, coiled tubes called **uriniferous tubules or nephrons**, held together by a connective tissue. Each tubule is

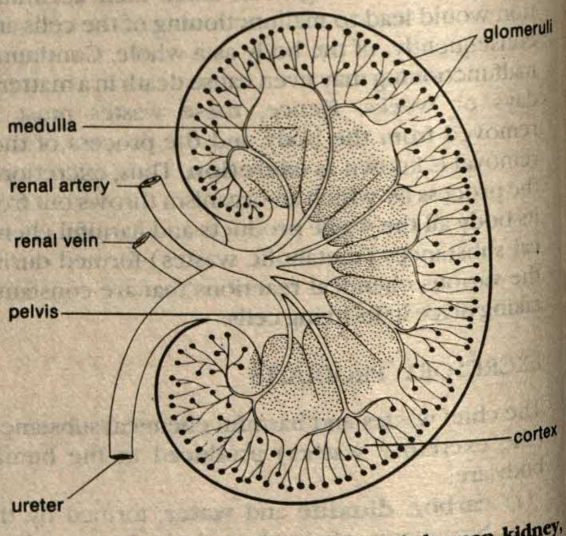


FIG. 22.2 Longitudinal section through human kidney, showing structure

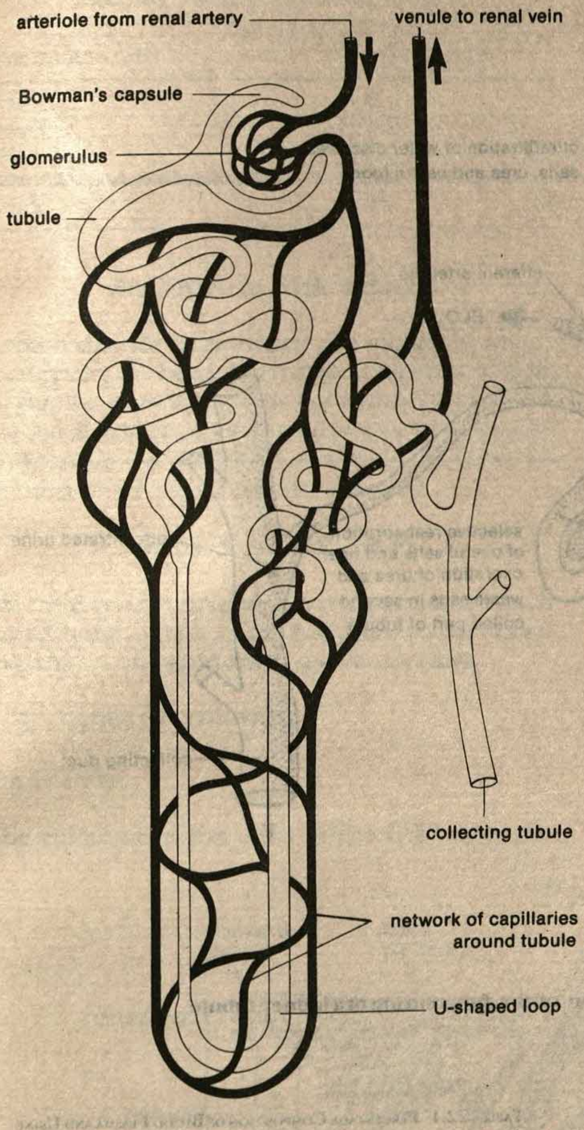


FIG. 22.3 Kidney tubule and its blood supply

blind (closed) at one end, and joins with other tubules at its other end, to form **collecting tubules** which open into the pelvis, from where the ureter begins. The blind end of the tubule lies in the cortex and is expanded to form a cup-like structure called **Bowman's capsule**. Each Bowman's capsule encloses a mass of capillaries which form a small bunch known as the **glomerulus**. The remainder of each tubule consists of a coiled part in the cortex, a U-shaped loop in the medulla, and another coiled part, again, in the cortex. The last portion of each nephron joins one of the numerous collecting tubules which open into the pelvis.

THE FORMATION OF URINE

A branch of the renal artery called the **efferent arteriole** divides repeatedly to form the bunch of capillaries called the glomerulus, in each of the Bowman's capsules [Figs. 22.3 and 22.4]. The blood leaves the glomerulus by means of an **efferent arteriole**. The smaller diameter of the efferent arteriole subjects the blood within the glomerulus to a higher pressure. Owing to the increased pressure, water and dissolved substances diffuse from the blood to the cavity of the capsule by a process known as **pressure filtration** or **ultrafiltration**. The filtrate in the capsule contains not only water with dissolved wastes like urea, uric acid, and harmful mineral salts but also useful food substances dissolved in the plasma so that the blood that leaves the glomerulus contains mainly the blood corpuscles and blood proteins together with some water. We cannot afford to lose the useful substances which get ultrafiltered (filtered under pressure). As the filtrate passes through the first coiled part of the tubule, the cells lining this region reabsorb food substances, salts, and water from the filtrate. As much material as possible is extracted and passed into the blood which circulates in the capillary network. Further, the cells lining the loop absorb as much water as possible from the filtrate, according to the needs of the body and pass it into the blood in the surrounding capillaries. In the second coiled part of the tubule, further useful substances that may have escaped reabsorption in the first coiled part are absorbed and passed into the blood stream, and also the excretory substances remaining in the blood are passed into the tubule. It is estimated that of the 1200 cm^3 of the fluid filtered per minute, only 1 cm^3 reaches the ureter as urine—over 99% of the filtrate is reabsorbed. According to another estimate, if the kidneys stopped reabsorbing water, complete dehydration of the body would result in less than three minutes. Kidneys, therefore, are not only important in excretion but are also extremely important organs for **osmo-regulation** (regulation of the water content of the body).

The remaining filtrate, now called **urine**, contains only the poisonous nitrogenous compounds, excess of mineral salts, and excess of water. The urine passes through the collecting tubule to the

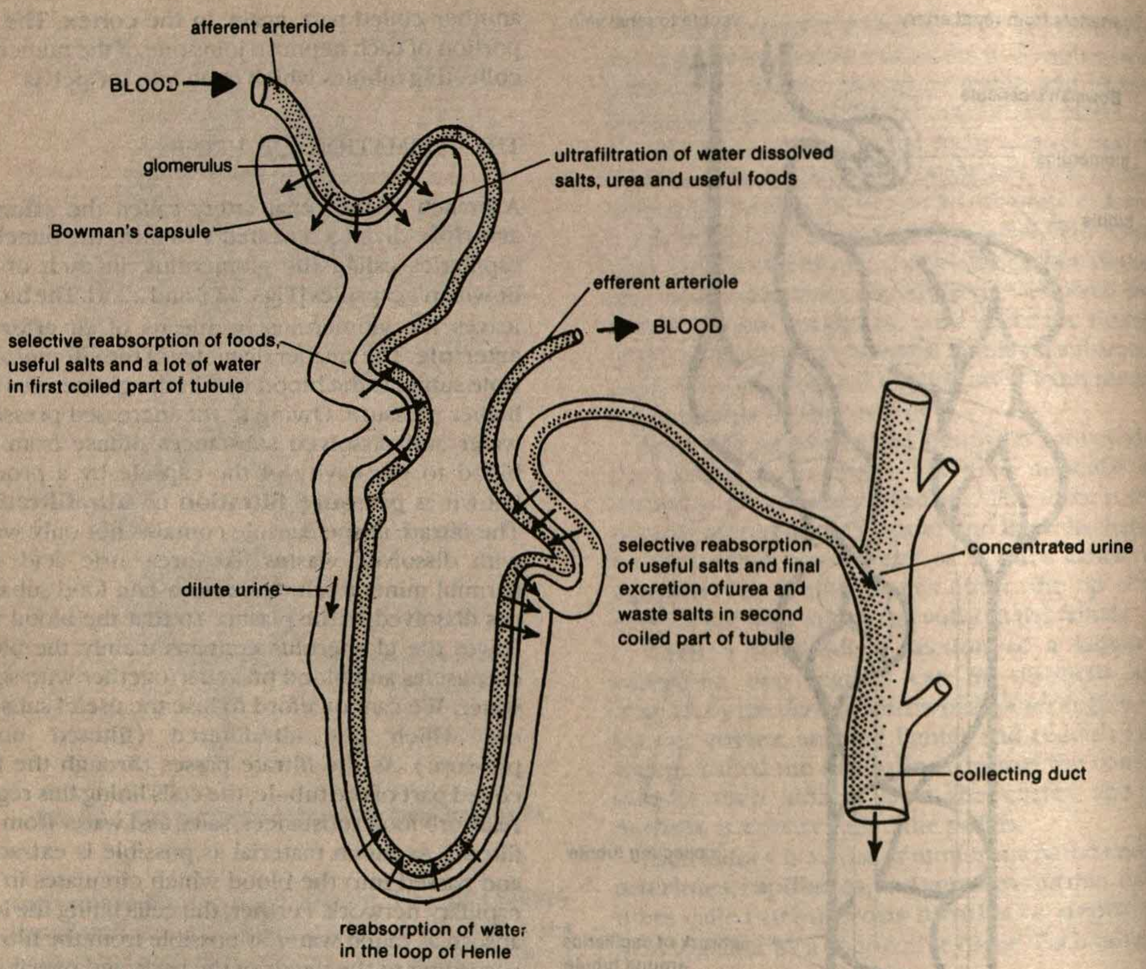

afferent arteriole
BLOOD
glomerulus
Bowman's capsule
ultrafiltration of water dissolved salts, urea and useful foods
efferent arteriole
BLOOD
selective reabsorption of foods, useful salts and a lot of water in first coiled part of tubule
dilute urine
selective reabsorption of useful salts and final excretion of urea and waste salts in second coiled part of tubule
concentrated urine
collecting duct
reabsorption of water in the loop of Henle

FIG. 22.4 Diagrammatic representation of the functioning of a kidney tubule

pelvis, from where it is carried by the ureter to the **urinary bladder**. The thin elastic and muscular wall of the bladder relaxes and the bladder expands to hold and store the urine. When the bladder becomes full, its walls contract, the ring of muscles at its neck or junction with the urethra relaxes, and the urine is forced out through the urethra.

Table 22.1 presents the comparative percentage compositions of blood plasma and urine and Table 22.2 lists the constituents of urine and their composition. It is quite clear that the major constituent of both blood plasma and urine is water, thereby emphasising its importance in the excretory process.

In humans, the average total quantity of urine passed out every day is about 1500 cm^3, but the quantity and composition of urine are greatly affected by conditions such as the amount of water consumed, the amount lost in sweating, and the temperature of the surroundings.

TABLE 22.1 PERCENTAGE COMPOSITION OF BLOOD PLASMA AND URINE

SOLUBLE CONTENTS	BLOOD PLASMA	URINE
Proteins, fats, etc.	7–9	0
Glucose	0.1	0
Ammonium compounds	0.001	0.04
Urea	0.03	2.0
Uric acid	0.004	0.05
Water	90–93	95

TABLE 22.2 COMPOSITION OF URINE (g/100 cm^3)

WASTE SUBSTANCE	PERCENTAGE
Urea	2
Uric acid	0.05
Mineral salts	1.6
Other nitrogenous compounds	0.2
Water	95

SECTION 3: THE LUNGS

Carbon dioxide is produced as a metabolic waste material by the breakdown of food substances such as glucose in all living cells during respiration. The carbon dioxide thus produced is removed from the body tissues by the blood as already explained in the chapter on the circulatory system.

SECTION 4: THE SKIN

The skin is a continuous covering of tissue which protects the surface of the body. It consists of two main layers, the **epidermis** and the **dermis.**

STRUCTURE OF THE SKIN

THE EPIDERMIS

The epidermis is the outer layer of the skin, and itself consists of three thin layers of cells [Fig. 22.5]. The outermost epidermal layer is the **cornified layer**, beneath which lie the **granular layer** and the **Malpighian layer**. The Malpighian layer consists of actively dividing living cells. The new cells produced here are continually pushed into the upper two epidermal layers, where they gradually die, lose their nuclei, and become flattened. They now get deposited with keratin, a tough horny protein. These new cells replace the cells lost from the cornified layer, which are constantly lost by the skin due to rubbing, friction, etc. The thickness of the cornified layer varies from one part of the body to another. For example, the cornified epidermal layer is very thick on the soles of the feet and on the palms of the hands, where the skin has to withstand considerable stress, pressure, and friction.

THE DERMIS

The dermis is a thick layer of connective tissue made up of elastic fibres, blood capillaries, lymph vessels, nerve fibres, sweat glands, and hair follicles [Fig. 22.5]. The lower region of the dermis contains cells with deposits of **subcutaneous fat**, which not only serves as a reserve of food, but, being a bad conductor of heat, also helps insulate the body against excessive loss of heat.

The **blood capillaries** supply the skin with the necessary food substances and oxygen and remove

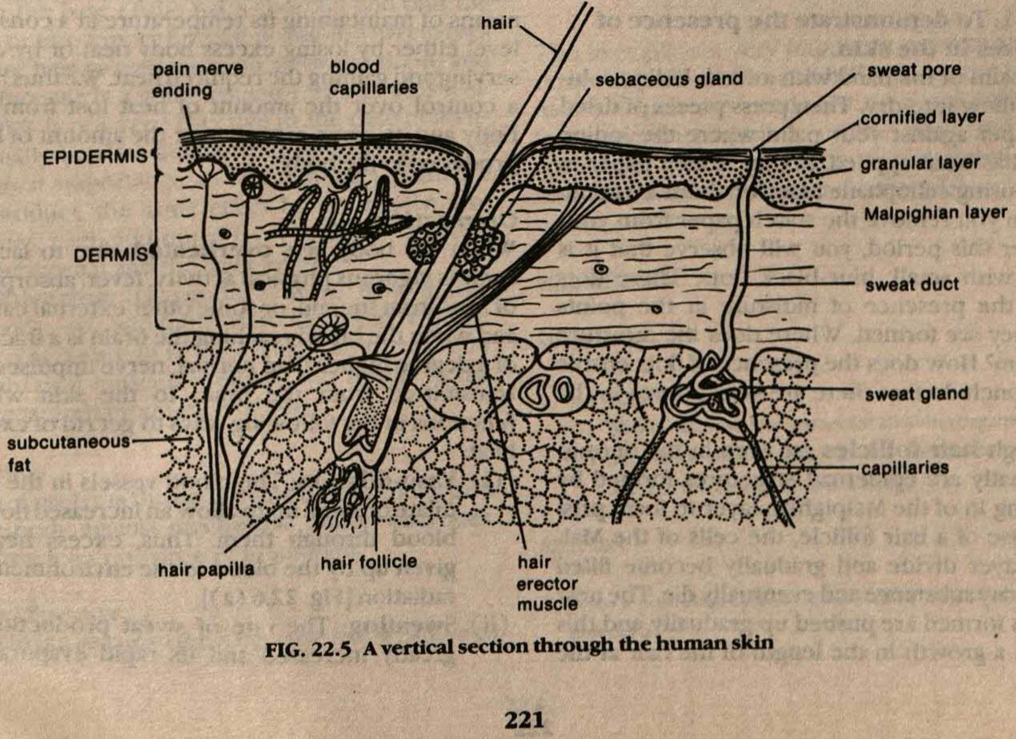


FIG. 22.5 A vertical section through the human skin

its excretory products. They also transport the harmful salts and excess of water to the sweat glands for removal from the body.

The **nerve fibres** form a network in the dermis. They terminate in nerve endings, which make the skin sensitive and enable it to respond to stimuli such as pain, pressure, heat, and cold, by sending messages to the central nervous system.

Sweat glands are distributed over most areas of the skin. A sweat gland consists of a coiled tube forming a mass. This coiled tubular mass receives the blood containing dissolved food substances, oxygen, excess of water, dissolved mineral salts (chiefly sodium chloride), and small quantities of urea. All these substances are absorbed from the blood by the sweat glands. The oxygen and the dissolved food substances are used for the normal functioning of the gland cells, and the remaining waste substances pass out from the skin in the form of **sweat**. The sweat formed in the sweat glands passes into the **sweat duct** which opens outwards at the surface of the skin in the form of **sweat pores**. The sweat evaporating from the surface cools the skin because the body gives up the latent heat required for vaporisation. Thus, in addition to the removal of the excess of water (osmo-regulation), harmful salts, and traces of urea, the sweat glands also serve to reduce and regulate the **body temperature.**

Activity 1: To demonstrate the presence of sweat pores in the skin.

Rub the palm of the hand with a weak iodine solution and allow it to dry. Then press pieces of dried starch paper against your palm where the iodine solution has been applied. Fix the starch paper in position, using cellophane tape, for about 10 minutes. When you remove the starch paper from your palm after this period, you will observe that it is covered with small, blue-black dots. These dots indicate the presence of moisture at the points where they are formed. Where does the moisture come from? How does the presence of dots enable you to conclude that there are sweat pores in the skin?

Although **hair follicles** are seen in the dermis, they actually are epidermal structures formed by the sinking in of the Malpighian layer to form **pits**. At the base of a hair follicle, the cells of the Malpighian layer divide and gradually become filled with a horny substance and eventually die. The new cells thus formed are pushed up gradually and this results in a growth in the length of the hair at the base of the hair follicle. This base, known as the **hair papilla**, obtains a rich supply of food substances and oxygen through a network of blood capillaries.

The hair follicle is always set at an inclined angle to the skin surface, so that the hair always projects obliquely from this surface. A few thin **muscle fibres** are attached to each hair follicle and the contraction of these fibres pulls the follicle straight and the hairs stand on end, a condition popularly called, 'goose flesh'.

Sebaceous glands open into the hair follicles. The oily secretions of these glands, called **sebum**, keep the hair and the skin soft and supple. They also form a water-proof and antiseptic film over the skin. The elasticity of the skin is due to the **elastic fibres** in the dermis, while firmness is due to **white fibres.**

FUNCTIONS OF THE SKIN

Regulation of Body Temperature

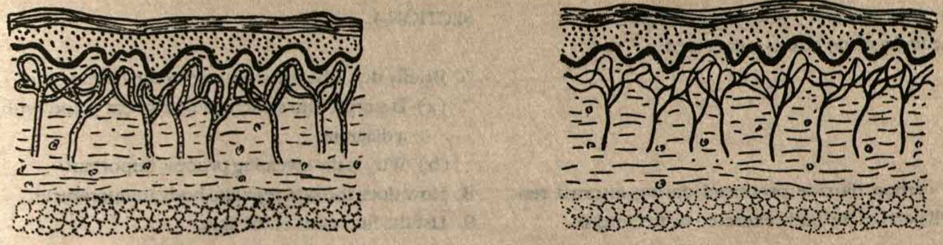
Like other mammals and birds, a human being is a **homoiothermic** (warm-blooded) animal. The body temperature of a human being remains almost constant at about 36.9°C, which is usually higher than that of the surroundings. The changes in the external temperature do not affect our body temperature. This is because our body has the means of maintaining its temperature at a constant level either by losing excess body heat or by conserving and gaining the required heat. We thus have a control over the amount of heat lost from the body and, to some extent, over the amount of heat produced in the body.

Overheating

When the body gets **overheated**, due to factors such as vigorous physical activity, fever, absorption of heat from the sun, or some other external causes and when the blood reaching the brain is a fraction of a degree higher than normal, nerve impulses are transmitted from the brain to the skin which functions in the following ways to get rid of excess heat:

(i) **Vaso-dilation**: The blood vessels in the skin dilate or swell up to allow an increased flow of blood through them. Thus, excess heat is given up by the blood to the environment by radiation [Fig. 22.6 (a)].

(ii) **Sweating**: The rate of sweat production is greatly increased and its rapid evaporation



(a) Vaso-dilation

(b) Vaso-constriction

FIG. 22.6 Diagrammatic representation of the functioning of the skin to show vaso-dilation and vaso- constriction

from the surface of the skin removes excess heat from the body.

Overcooling

When the body loses more heat than the amount being formed within it, the body temperature **falls** immediately. As soon as this happens, the brain sends nerve impulses to the skin which functions in the following ways to conserve the body heat:

(i) **Vaso-constriction**: The blood capillaries near the surface of the skin become narrow, so that less blood flows through them and less heat is lost by the blood to the surroundings by radiation and convection [Fig. 22.6(b)].

(ii) **Sweat**: The rate of the production of sweat is greatly reduced.

(iii) **Hair positioning**: The hair erector muscles at the base of the hairs contract and pull the hair into a more upright position. This enables the hair to trap more air between them, and since air is a good insulator, less heat is lost. This is not very effective in the case of a virtually hairless animal such as man, but is of great importance to furry animals. Man can produce the same effect by putting on clothes; each additional layer of fabric traps air between it and the layer below.

(iv) **Shivering**: To produce more heat in the body, we suddenly start shivering without being aware of it. Shivering is an involuntary physical muscular activity and results in the increased production of heat.

PROTECTION

The skin protects the underlying tissues and organs of the body against mechanical injury, microbes, and ultraviolet rays present in sunlight.

SENSORY FUNCTION

The skin is a sensory organ because it is sensitive to the stimuli of factors such as heat, cold, pain, touch, and pressure.

EXCRETION

The skin serves as an important excretory organ and the sweat glands remove metabolic wastes and excess of salts from the body.

OTHER FUNCTIONS

The skin helps in regulating the water content of the body by osmo-regulation. It also serves as a storage organ for subcutaneous fat which is stored in the deeper layers of the dermis. Finally, it helps in the synthesis of vitamin D (essential for the formation of the bones and teeth) when exposed to sunlight.

SECTION 5: THE LIVER

The liver plays a very important excretory role in removing **biliverdin** and **bilirubin**—the bile pigments which are produced as waste substances from the haemoglobin of the dead red blood corpuscles. These pigments are excreted in the bile, as already explained in Chapter 19.

EXERCISES

SECTION 1

1. (a) What is excretion?
   (b) Why is excretion necessary for all living organisms?
   (c) List the excretory organs and the chief excretory products in the case of a human being.

SECTION 2

2. Draw a neat diagram of a human kidney and label its important parts.

3. Describe the structure and working of a nephron.
4. How is urine formed and how is it excreted?

SECTION 3

5. How is the carbon dioxide produced during internal respiration in all parts of the body excreted by the lungs?

SECTION 4

6. Briefly describe the structure of the human skin.
7. (a) Describe the structure of a sweat gland with the aid of a diagram.
   (b) Why is the sweating process important?
8. How does the skin regulate body temperature?
9. List the functions of the skin.

CHAPTER 23

Support and Movement in Man

SECTION 1: IMPORTANCE AND FUNCTIONS OF THE SKELETON

Imagine a man without a skeleton inside his body. In such a case, he would merely be a fleshy lump, unable to stand up and support himself. The framework needed to support the body and to keep its shape is provided by the **skeleton** [Fig. 23.1]. Some of the most delicate and important internal organs, e.g., the brain, the spinal cord, the heart, and the lungs, are enclosed by a casing of bones: the brain is enclosed in the **cranium**; the spinal cord in the **vertebral column**; and the heart and lungs are surrounded by a cage of **ribs**, supported by the **sternum** in front and the **vertebral column** at the back. These important organs are protected from damage in this manner. The skeleton is not a one-piece structure; it is made up of a number of separate bones, which are jointed and movable with respect to one another in varying degrees. Movements of the body parts are carried out by the action of muscles which are attached to the bones.

FUNCTIONS OF THE SKELETON

The functions of the skeleton may be summed up as follows:

(1) It provides a framework to support the body and helps maintain its shape.
(2) It protects from damage some of the important internal organs such as the heart, lungs, spinal cord, and brain.
(3) It provides the base for the attachment of muscles and forms levers for muscle action which produces movement in the different parts of the body.
(4) Some of the bones, e.g., the ribs, skull, and vertebrae, manufacture red blood corpuscles and white blood corpuscles in their marrow.
(5) It acts as a storehouse of minerals.

SECTION 2: THE STRUCTURE OF THE SKELETON

The human skeleton [Fig. 23.1] consists of 206 bones altogether. These bones belong to different groups, as follows:

(a) **The axial skeleton**, comprising the skull and the vertebral column.
(b) **The appendicular skeleton**, comprising the skeleton of the limbs and girdles.
(c) The **ribs** and the **sternum**.

THE AXIAL SKELETON

The Skull

The skull is located at the top of the vertebral column. It is composed of several bones, joined together by **immovable suture joints** [Fig. 23.2]. It consists of the **cranium** (the 'brain box') and **capsules** for the sense organs of hearing, sight, and smell. Besides these, the **jaws** are also supported by the skull; the **upper jaw** is completely fused to the

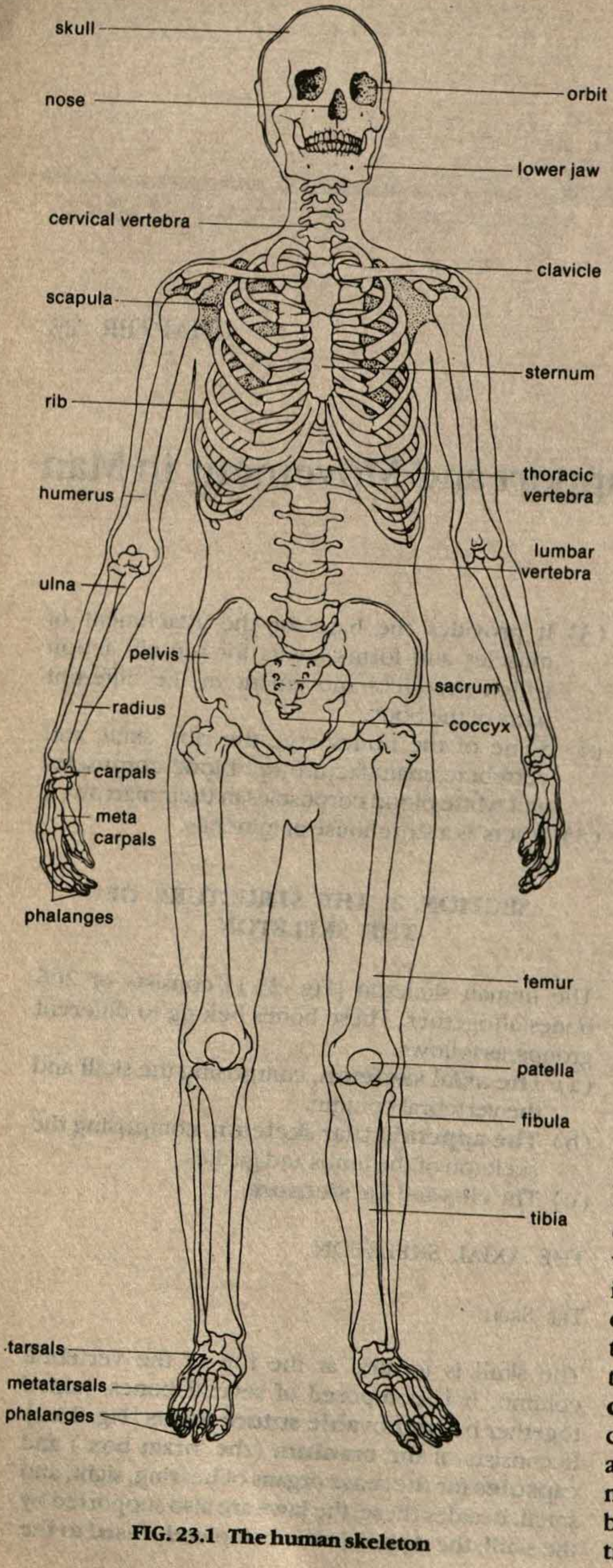


FIG. 23.1 The human skeleton

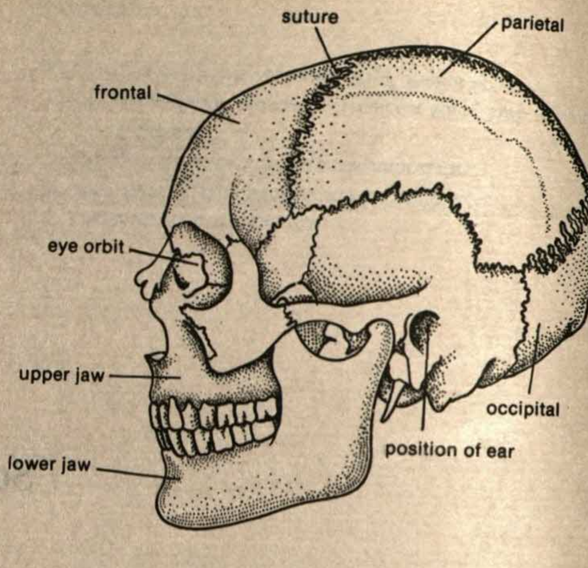


FIG. 23.2 The human skull

underside of the cranium, while the movable **lower jaw** is hinged to it.

The cranium, which encloses the brain, has a hole at its back which is called the **foramen magnum**. It is through this hole that the **medulla oblongata** of the brain continues downwards in the form of the **spinal cord** which is enclosed in the vertebral column.

The Vertebral Column

The vertebral column or the **backbone** encloses the spinal cord and protects it from damage. It also supports the head, neck, and body [Fig. 23.3]. It is composed of 33 small bones called **vertebrae**, placed end to end, which enclose a hollow tube called the **neural canal**, through which the spinal cord runs. The number and distribution of the vertebrae are as follows: Seven **cervical vertebrae** in the neck; twelve **thoracic vertebrae** at the back of the chest; five **lumbar vertebrae** at the back of the abdomen; five **sacral vertebrae** fused together to form the sacrum in the hip region; and four **caudal vertebrae** fused together to form a little tail called the **coccyx**. **Discs** or pads of cartilage which act as shock absorbers and allow very limited movement are present at the joints between the vertebrae. The vertebrae are bound together by tough tissues called **ligaments**.

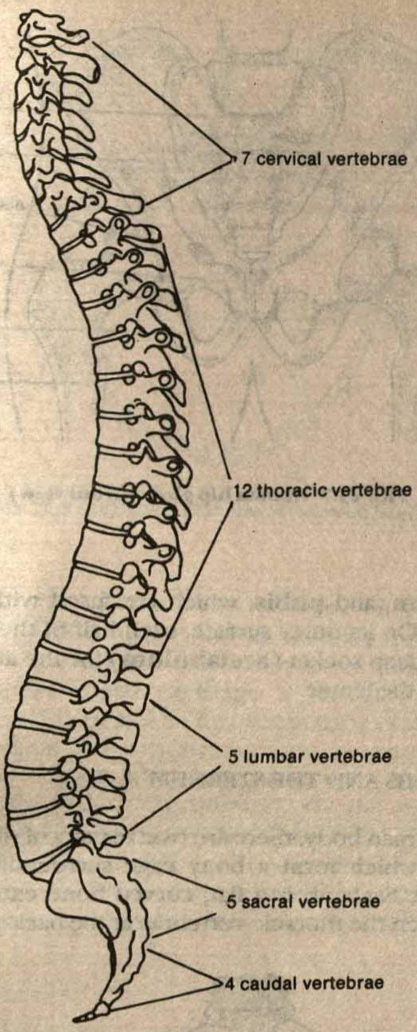


FIG. 23.3 Vertebral column of human being

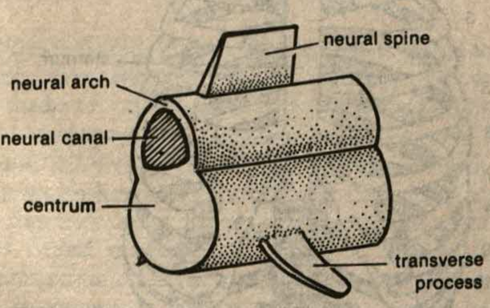


FIG. 23.4 The basic plan of a vertebra

The basic plan of each vertebra is the same, despite modifications arising due to different positions and functions along the length of the vertebral column. Each vertebra is made up of a solid cylindrical body called the **centrum**, which carries **a neural arch, a neural spine, a neural canal**, and a pair of **transverse processes** [Fig. 23.4].

THE APPENDICULAR SKELETON

The Limbs

In all limbed vertebrates, the limbs have the same basic arrangement of bones. The skeleton of each of the four limbs is based on a similar plan, i.e., the **pentadactyl plan** [Fig. 23.5].

Human beings have two forelimbs (arms) and two hind limbs (legs). Each **forelimb** consists of the following bones:

(1) One **humerus** in the upper arm.
(2) One **radius** (towards the side with the thumb) and one **ulna** in the lower arm.
(3) Eight small **carpals** in the wrist.
(4) Five **metacarpals** in the palm.

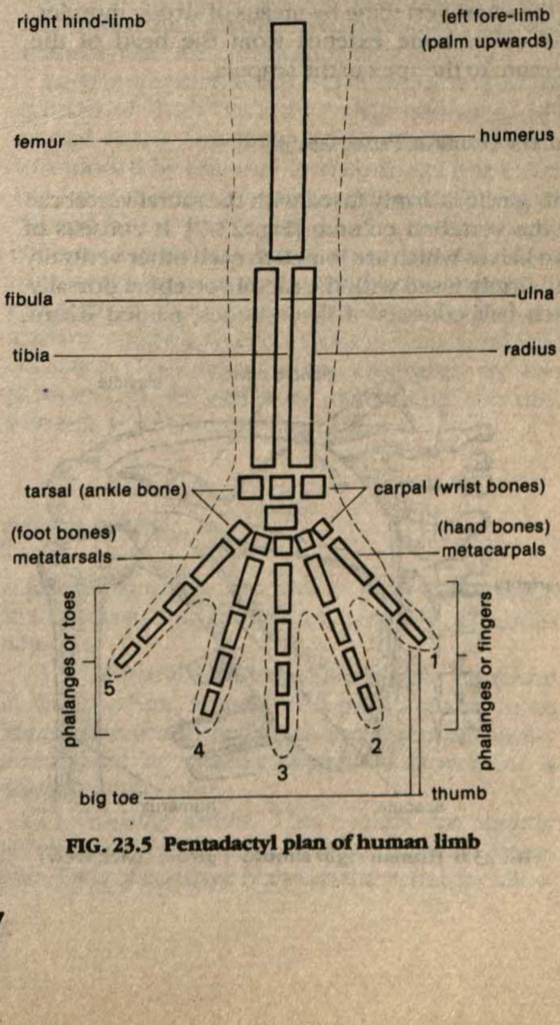


FIG. 23.5 Pentadactyl plan of human limb

(5) Five **digits** or **fingers**, each having three bones called **phalanges** (except the thumb, which has only two phalanges).

Each **hind limb** has the following bones:

(1) One **femur** in the thigh.
(2) One **tibia** (towards the great toe) and one **fibula** in the shin.
(3) Seven **tarsals** in the ankle.
(4) Five **metatarsals** in the sole.
(5) Five **digits** or **toes**, each having three phalanges (except the great toe which has only two).
(6) One **knee cap (patella)** in front of the leg.

The Shoulder Girdle or Pectoral Girdle

This girdle consists of two halves and each half consists of two bones, the **shoulder blade (scapula)** at the back and the **collar bone (clavicle)** in the front [Fig. 23.6]. The scapula is large and roughly triangular in shape and has a socket (**glenoid cavity**) at its apex for the **articulation** of the humerus. It has no bony connection with the vertebral column, but is fixed to the neural spines of the chest vertebrae by means of strong muscles. The collar bone extends from the head of the sternum to the apex of the scapula.

The Hip Girdle or Pelvic Girdle

This girdle is firmly fused with the sacral vertebrae of the vertebral column [Fig. 23.7]. It consists of two halves which are joined to each other ventrally and firmly fused with the sacral vertebrae dorsally Each half consists of three bones, named **ilium**, **ischium**, and **pubis**, which are fused with each other. On its outer surface, each half of the girdle has a deep socket (**acetabulum**) for the articulation of the femur.

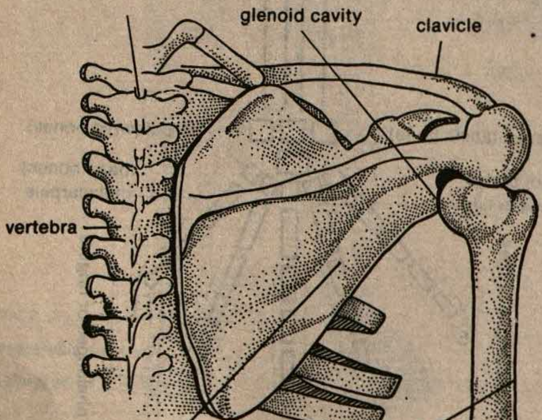


FIG. 23.6 Human right shoulder girdle (back view)

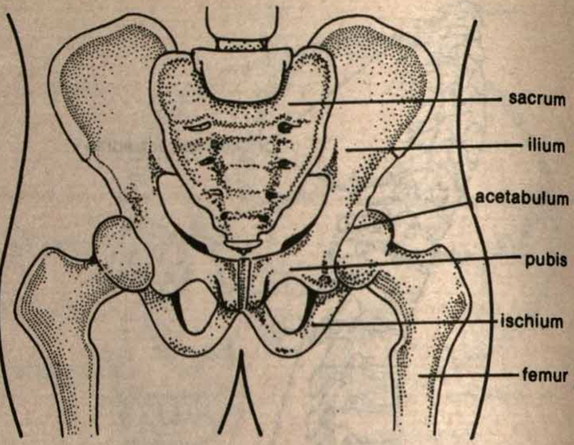


FIG. 23.7 Human hip girdle (front view)

THE RIBS AND THE STERNUM

In a human body, there are twelve pairs of ribs [Fig. 23.8] which form a bony cage surrounding the thorax. Each rib is a flat, curved bone extending between the thoracic vertebrae at the back and the

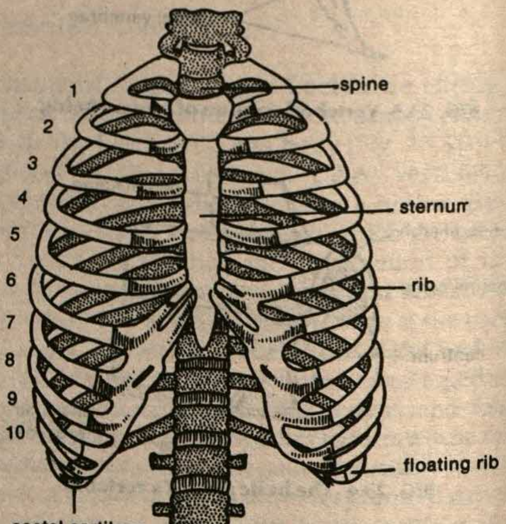


FIG. 23.8 Human ribs and sternum

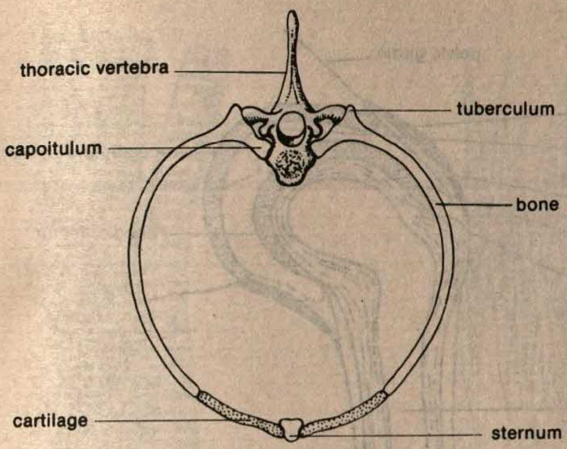


FIG. 23.9 **Ribs and their attachment viewed from above**

dagger-shaped sternum (breastbone) lying in the mid-ventral line of the thorax. Its bony vertebral portion is articulated with a thoracic vertebra and the flexible **costal cartilage** is attached to the sternum [Fig. 23.9]. The first seven pairs of ribs are directly attached to the sternum and are called **true ribs**. The eighth, ninth, and tenth pairs are indirectly attached to the sternum via the seventh costal cartilage, and are called **false ribs**. The last two pairs, that is, the eleventh and twelfth, are short and have no connection whatsoever with the sternum. Consequently, they are called **floating ribs**.

SECTION 3: BONES AND JOINTS

BONES

Although brittle, hard, and rigid, **bones** are very much alive. Like other structures in the body, they are made up of cells and are provided with lymph and blood vessels and nerve fibres. They grow in a manner similar to the softer parts of the body. If they get broken, the two parts are capable of growing together again. Bones are composed of bone cells called **osteoblasts**, scattered in a ground substance called the **matrix**. Osteoblasts are arranged in concentric rings around a central canal called the **Haversian canal** [Fig. 23.10] which contains nerve fibres, lymph, and blood vessels; the blood vessels bring necessary materials required for the osteoblasts. Osteoblasts are stellate cells which are linked together by tiny strands of cytoplasm. These cells secrete calcium salts—chiefly calcium phosphate—which fill up the matrix around them and make the bones hard, rigid, and strong structures and also opaque to X-rays.

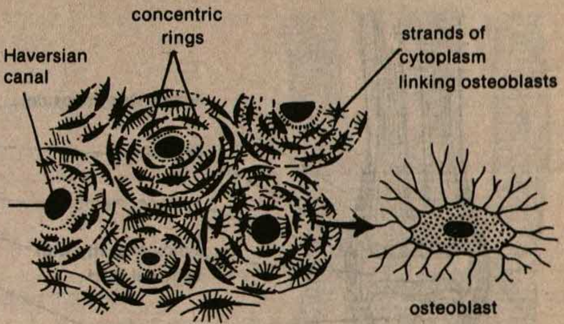


FIG. 23.10 **Transverse section of bone showing Haversian system**

Bones are surrounded by membranes (periosteum) containing fibrous tissues and blood vessels. The periosteum gives rise to osteoblasts and also acts as a plane for the attachment of muscles.

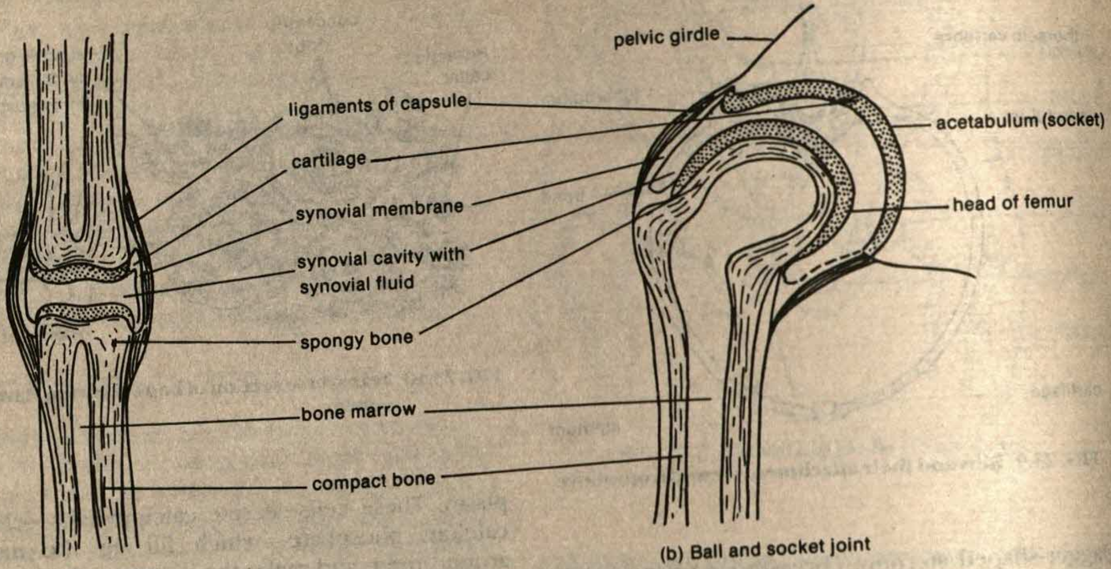
Long bones such as those of limbs are hollow and cylindrical. They have their shaft composed of a central cavity containing **yellow bone marrow** surrounded by external hard **compact bone**. Yellow bone marrow is composed of a soft fatty material and blood vessels. The head of these bones is composed of **spongy bone** with a superficial layer of compact bone around it. **Red bone marrow** is present in the spongy part of the bone. In this bone marrow, red blood corpuscles are being produced constantly. Further, red blood corpuscles are also produced in the red bone marrow of the ribs, sternum, vertebrae, etc.

JOINTS

A **joint** is formed where two or more bones meet. In the human body, there are three main categories of joints:

(1) **Immovable joints**: These joints are found in the cranium, sacrum, and pelvic girdle. In an immovable joint, the bones meet and are firmly interlocked by saw-like edges. No movement is possible at this joint.

(2) **Gliding joints**: These joints are slightly movable and are present between adjacent vertebrae. Pads of cartilage between the vertebrae allow



(a) Hinge joint

(b) Ball and socket joint

FIG. 23.11 Movable joints

only a very limited degree of movement of the bones at these joints.

(3) **Movable or synovial joints**: These joints occur typically in the limbs and allow the maximum degree of movement of the bones. Movable joints are further divided into three types:

(i) Hinge joints, which allow movement in one plane only. In other words, only a movement through an angle of 180° between the ends of bones is possible. These joints are found in the knees, elbows, fingers, etc. [Fig. 23.11(a)].

(ii) Ball and socket joints, which allow the maximum degree of movement between the ends of the bones. In this case, the movement is rotatory and is possible in all planes [Fig. 23.11(b)]. Examples of such joints are those found between the humerus and the shoulder girdle and those between the femur and the pelvic girdle. The rounded ball-like heads of the humerus and the femur fit into cup-like sockets in the shoulder and the hip girdles, respectively.

(iii) Pivot joints, which allow rotation about an axis. It is this type of joint which enables one to turn one's head from side to side.

The basic structure of a joint is quite complex. Here, the bones are held together by an elastic connective tissue called a **ligament.** When the jointed bones move, the ligament is stretched according to the amount of movement. The whole joint is enclosed in a sheath of strong, fibrous tissue called the **joint capsule.** On the inner side of the joint capsule is a lining of a fine membrane called the **synovial membrane**. Again, in the case of a joint, the ends of the bones are covered with a tough, smooth, slippery cartilage. The smooth and slippery surface of this cartilage helps reduce friction between the bones during movement. The joint capsule contains the **synovial fluid** which not only lubricates the joint, thereby further reducing the friction during movement, but also functions to hold the bones in place in the joint.

SECTION 4: MUSCLES

STRUCTURE AND TYPES OF MUSCLES

Muscles are bundles of elongated cells called **muscle fibres.** These bundles are enclosed in sheaths of connective tissue. The muscles can shorten or lengthen themselves but cannot expand. When a muscle is shortened, it becomes thicker, and when lengthened it regains its original shape and size.

Depending upon their distribution in the body, two types of muscles, namely, voluntary and involuntary, can be distinguished [Fig. 23.12].

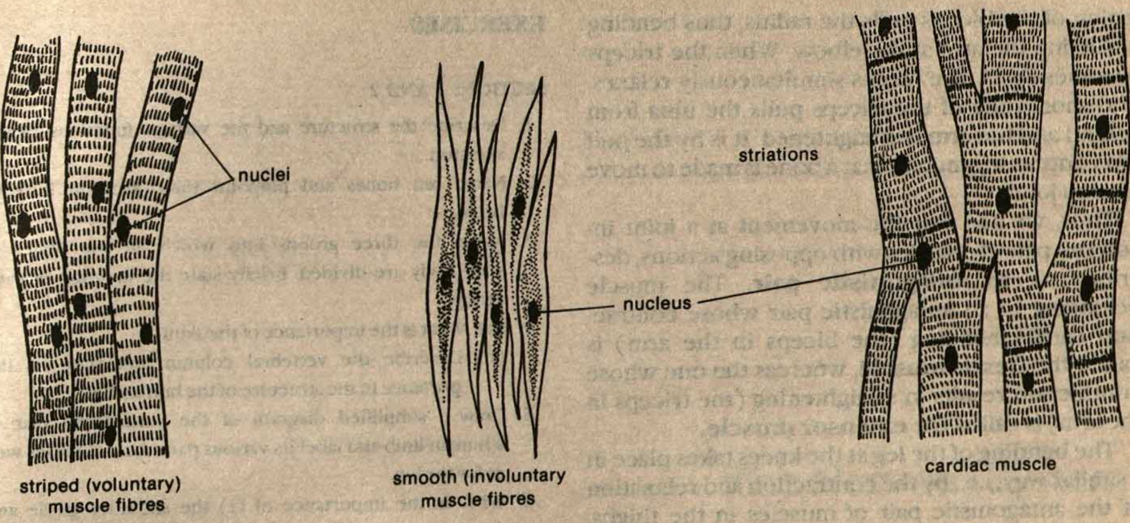


FIG. 23.12 Types of muscles

VOLUNTARY MUSCLES

The muscles, commonly known to us as 'flesh', form the bulk of the meat that we purchase from a butcher's shop. These muscles surround the bones and, hence, are also called **skeletal muscles**. They are responsible for the movements of bones at joints. The working of these muscles can be wilfully controlled and, hence, they are said to be 'voluntary' muscles, although they may also work involuntarily as a result of reflex action. Voluntary muscles, as in the arms, legs, and shoulders, are seen to be multinucleate and striped—these stripes or striations comprise bands of light and dark regions. These muscles are capable of very powerful contractions, but are easily fatigued.

INVOLUNTARY MUSCLES

These muscles are found in the internal organs of the body such as the stomach, intestines, blood vessels, eye, and heart. These muscles are capable of less powerful, but longer acting contractions. Their working is not under the control of the will, hence their name.

Involuntary muscles are seen to be **smooth** as in the lining of the stomach, small intestine, and urinary bladder, or striped as in the heart (**cardiac muscles**). Although similar to the striped muscles, the cardiac muscles are involuntary. Their fibres are joined to each other by cross-connections. Their contractions are slower, less powerful, rhythmic, and they are not easily fatigued.

MUSCLES IN RELATION TO THE SKELETON

Each end of a muscle is drawn out to form a tough and inelastic cord called a **tendon** [Fig. 23.13]. Bones are moved by muscles which are attached to their periosteum by these tendons. At one end, a muscle is attached with the help of tendons to a bone which does not move when the muscle contracts; this end is called the **origin** of the muscle. The other end is attached to a bone which moves; this end is called the **insertion** of the muscle.

A muscle can pull the bone only in one direction. For example, in the upper arm, two large muscles (the **biceps** in front of the upper arm and the **triceps** behind it) help control the movement at the elbow joint [Fig. 23.13]. The biceps is attached to the scapula by two tendons at its origin, while, at the insertion, it is attached to the radius. The triceps has three tendons at this origin, one attached to the scapula and the other two to the humerus. At its insertion the triceps is attached to the ulna.

The movement of the arm takes place as follows: On receiving a nerve impulse from the central nervous system, the biceps contracts, becoming shorter and thicker. Simultaneously, the triceps relaxes. Since the tendons do not stretch, the shortening of the biceps pulls the radius, thus bending or flexing the arm at the elbow. When the triceps becomes short, the biceps simultaneously relaxes. The shortening of the triceps pulls the ulna from behind and the arm is straightened. It is by the pull of a contracting muscle that a bone is made to move about a joint.

Thus, we see that the movement at a joint involves a pair of muscles with opposing actions, described as an **antagonistic pair.** The muscle belonging to an antagonistic pair whose contraction causes bending (the biceps in the arm) is called the **flexor muscle**, whereas the one whose contraction results in straightening (the triceps in the arm) is called the **extensor muscle.**

The bending of the leg at the knees takes place in a similar way, i.e., by the contraction and relaxation of the antagonistic pair of muscles in the thighs, when they receive the necessary nerve impulses from the central nervous system. (See Table 23.1).

TABLE 23.1 THE WORKING OF THE LEG MUSCLES

MUSCLE	ORIGIN	INSERTION	ACTION
1. Quadriceps	Pelvic girdle and femur	Tibia	Extends leg at knee
2. Biceps	Pelvic girdle and femur	Fibula	Flexes leg at knee
3. Calf muscle	Femur	Tarsal (heel bone)	Extends leg at ankle
4. Tibial muscle	Tibia	I Metatarsal	Flexes leg at ankle

EXERCISES

SECTIONS 1 AND 2

1. Describe the structure and the various functions of the skeleton.
2. Name ten bones and pinpoint their location in your body.
3. Name the three groups into which all the bones of your body are divided. Briefly state the function of each group.
4. (a) What is the importance of the skull?
   (b) Describe the vertebral column and state its importance in the structure of the human body.
5. Draw a simplified diagram of the pentadactyl plan of a human limb and label its various parts for the arm as well as for the leg.
6. What is the importance of (i) the shoulder girdle and (ii) the pectoral girdle?
7. Describe the structure of the rib cage, and state its functions and importance.

SECTION 3

8. (a) What are bones? What are their constituents?
   (b) What are red marrow and yellow marrow and where are they found?
9. Name the various types of joints found in the human body. Give an example of each joint and name the bones involved in each case.
10. Describe the structure of a typical joint.

SECTION 4

11. Name the different muscles in your leg and explain how they work in the movement of the leg while walking.
12. State, with relevant examples, the differences between: (a) tendons and ligaments; (b) origin and insertion of a muscle; and (c) flexor muscle and extensor muscle.

CHAPTER 24

The Nervous System

SECTION 1: IMPORTANCE, FUNCTIONS, AND STRUCTURE OF THE NERVOUS SYSTEM

The **nervous system** may be regarded as the 'supreme commander' controlling all the activities in the body, and is vital for each and every activity of all organic systems. The nervous system consists of the **brain**, the **spinal cord**, and the **nerves**. We now discuss the functions performed by the nervous system.

First of all, the nervous system controls and coordinates the activities of the various parts of the body so that all of them work together as a team to eliminate confusion, disorder, or chaos. For example, the following activities take place in the body while running:

(a) the legs are moved alternately in a definite order;
(b) to meet the increased need for energy during running, the rate of breathing is increased for taking in more oxygen needed for the oxidation of food substances during respiration;
(c) the heart beats faster to transport oxygen and food substances to the tissues at a quicker speed; and
(d) to avoid overheating of the body, the rate of sweat production is increased so that excess heat may be got rid of by the evaporation of sweat.

All these activities occur in a proper sequence due to the correct coordination of the concerned parts of the body, which is achieved by the nervous system.

Secondly, the nervous system is also responsible for keeping us aware of the changes in our surroundings and enables us to react to such changes by performing the actions necessary for our safety and survival; i.e., it enables us to respond to the various external stimuli. For example, the sight of a snake (the **stimulus**) quickly compels one either to run away or to look for a defensive weapon to guard against possible attack (the **response**).

For receiving the information regarding changes in the surroundings, our body is provided with special **sense organs** called the **receptors**, e.g., eye, ear, lining inside the nose, tongue, and skin. From the receptors, information is conveyed to the brain or spinal cord by means of **nerves**. From the brain or spinal cord, the required message is sent by nerves to the organs of the body which are required to react. The muscles and glands which help us react or respond to stimuli are known as **effector organs**. The nervous system provides suitable links between the receptor organs and the effector organs.

In studying the nervous system, it is convenient to break it up into three parts:

(i) **the central nervous system (CNS)**, consisting of the brain and the spinal cord;
(ii) **the peripheral nervous system (PNS)**, which includes the various nerves going to and leading out from the CNS;
(iii) **the autonomic nervous system (ANS)**, consisting of **sympathetic** and **parasympathetic** nerves from the CNS which control the

working of the involuntary organs of the body such as the heart, stomach, intestine, kidneys and bladder.

The CNS and PNS are coordinated to control the functions of the voluntary organs of the body, whereas the ANS independently controls the functions of the involuntary internal organs. The behaviour of these systems is represented in the chart now given.

Receptor organs ⟶ Peripheral nervous system ⟶ Central nervous system ⟶ Peripheral nervous system ⟶ Effector organs

↓

Sympathetic nerve cords and parasympathetic nerves ⟶ Involuntary organs of the body

SECTION 2: NERVOUS TISSUE

NEURONES

All the parts of the nervous system are made up of nervous tissue, which is a group of highly specialised cells called **nerve cells** or **neurones** [Fig. 24.1].

The function of neurones is to transmit nerve impulses. There are three types of neurones, which are now described:

(i) Motor neurones: This type of neurone transmits impulses from CNS to a muscle [Fig. 24.1]. In spite of its peculiar shape, it has the same basic structure as that of other cells in the body. The neurone also has a nucleus, cytoplasm, mitochondria, cell membrane, etc. Its cell body, the part with a nucleus, is situated in the CNS and is connected with the neighbouring neurones by arm-like projections called **dendrons**, which have branched terminal dendrites. One of the projections (the **axon**) is very long, and passes through a nerve. It bears terminal dendrites situated in a muscle or a gland (the effector organs). The axon contains **axoplasm** which is continuous with the cytoplasm of the cell body. The cell membrane of the cell body extends around the axon also. The axon is enclosed in a fatty **myelin sheath** which is surrounded by a thin membrane called **neurilemma**—the cell membrane of the adjoining Schwann cell. The myelin sheath insulates the axon and also speeds up the transmission of impulses. However, this sheath is interrupted by constrictions called **nodes of Ranvier**. In some neurones, the myelin sheath may not be present at all.

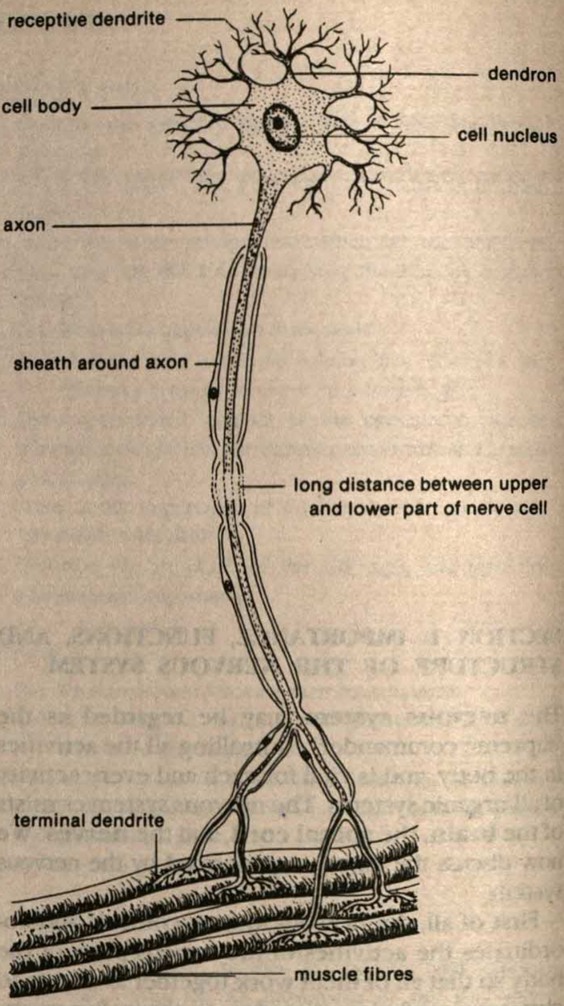


FIG. 24.1 Structure of neurone

The path followed by the impulses in a motor neurone is as follows:

Dendrites of the cell body in CNS ⟶ cell body ⟶ axon ⟶ terminal dendrites in an effector organ (muscle or gland).

(ii) Sensory neurone: In a sensory neurone, there is a dendron which is extremely long and is continuous with the **axon** of the cell [Fig. 24.2]. At the junction of the axon and the dendron, the cell body is connected by a short stalk. Both the dendron and the axon have branched ends. The end of the dendron branches into **dendrites**, which are situated in a receptor organ; these dendrites are known as **receptor dendrites**.

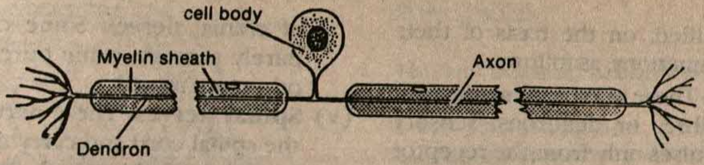


FIG. 24.2 A sensory neurone

The end of the axon branches into **terminal dendrites**, which are situated in the CNS. Sensory neurones conduct **nerve impulses (sensations)** from the receptor organs towards the CNS (brain or spinal cord). The path followed by nerve impulses through a sensory neurone is as follows:

> Receptor dendrites in a receptor organ⟶ dendron⟶cell body ⟶ axon ⟶terminal dendrites in CNS

(iii) Intermediate (bipolar) neurones: These neurones are present only in the CNS [Fig. 24.3], where they connect sensory and motor neurones with each other, and also with other neurones in the CNS.

NERVES

Nerves are made up of a large number of **nerve fibres**, dendrons or axons or both, all running parallel to each other without branching or joining, just like the several strands of metallic wires in a multicore electric cable [Fig. 24.4]. Some of the nerve fibres in a nerve conduct impulses from the receptor organs to the CNS, while others conduct impulses from the CNS to the effector organs. It should be noted that a particular nerve fibre always conducts nerve impulses in the same specific direc-

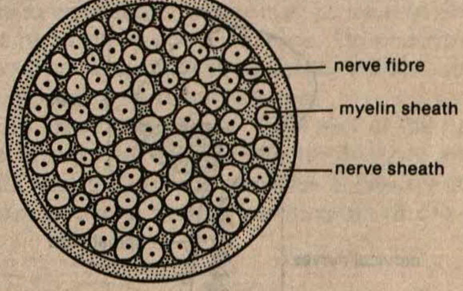
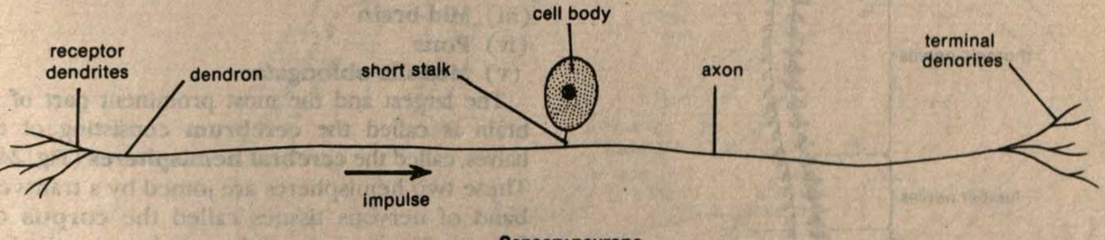
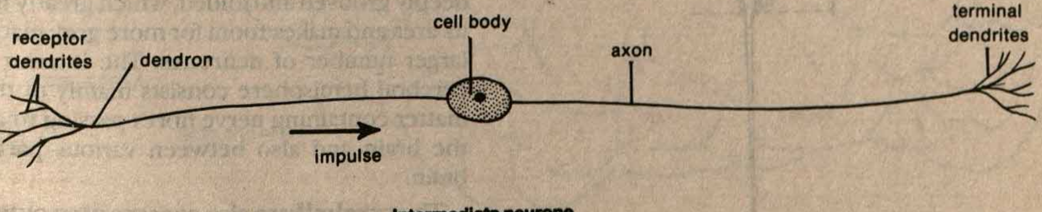


FIG. 24.4 A nerve in transverse section



Sensory neurone



Intermediate neurone

FIG. 24.3 Sensory and intermediate neurones

tion. Nerves are classified, on the basis of their origins, positions and functions, as follows:

(i) **Sensory nerves**: These nerves are made up of sensory nerve fibres or dendrons. Sensory nerves carry impulses only from the receptor organs to the CNS.

(ii) **Motor nerves**: These nerves are made up of motor nerve fibres or axons. Motor nerves conduct impulses only from the CNS to the effector organs.

(iii) **Mixed nerves**: Mixed nerves consist of sensory as well as motor nerve fibres, i.e., dendrons as well as axons. These nerves carry impulses in both directions, i.e., from the receptor organs to the CNS as well as from the CNS to the effector organs.

(iv) **Cranial nerves**: These nerves originate from the brain and carry the nerve impulses to and from the brain. Human beings have **12 pairs** of cranial nerves. Some cranial nerves are purely sensory, some purely motor, and yet others are mixed.

(v) **Spinal nerves**: These nerves originate from the spinal cord and carry the nerve impulses to and from the spinal cord. Human beings have **31 pairs** of spinal nerves. All spinal nerves are mixed nerves.

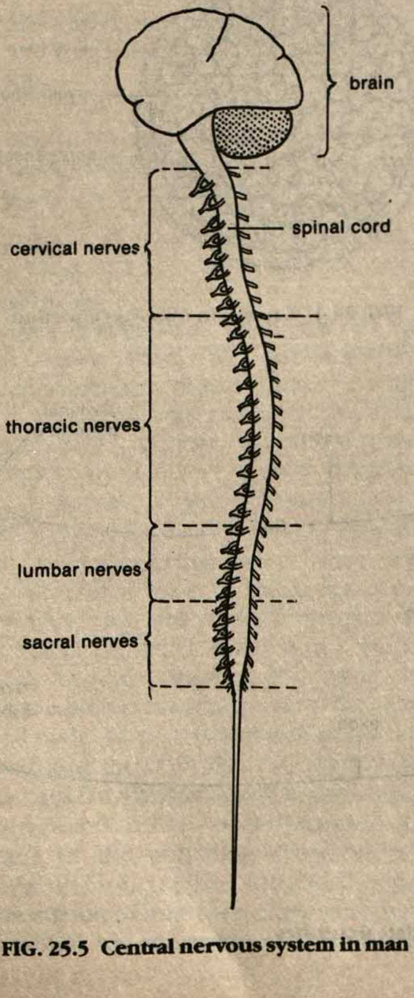


FIG. 25.5 Central nervous system in man

The functions of the sensory and motor nerves are depicted in the chart as follows:

SECTION 3: THE BRAIN

STRUCTURE OF THE BRAIN

The human brain is enclosed within, and protected by, the bones of the skull. The brain contains millions of neurones and weighs approximately 1350 g (roughly 1/50 of a person's total weight). It is hollow from within and the central space is filled by a nourishing lymph-like fluid called the **cerebrospinal fluid**. This fluid is also enclosed in between the thin end membranes—meningeal membranes—which surround the brain and provide it protection by cushioning.

The brain is composed of both **grey** and **white matter**, which are the reasons containing neurones and nerve fibres, respectively. The grey matter lies on the outside and the white matter on the inside.

The brain consists of the following parts:

(i) **Cerebrum**
(ii) **Cerebellum**
(iii) **Mid-brain**
(iv) **Pons**
(v) **Medulla oblongata**

The largest and the most prominent part of the brain is called the **cerebrum** consisting of two halves, called the **cerebral hemispheres** (Fig. 24.6) These two hemispheres are joined by a transverse band of nervous tissues called the **corpus callosum**. The surface of the cerebrum, called the **cerebral cortex**, consists of grey matter and is deeply grooved and folded, which greatly increases its area and makes room for more grey matter and a larger number of neurones. The interior of each cerebral hemisphere consists mainly of the white matter containing nerve fibres passing to and from the brain and also between various parts of the brain.

The **cerebellum** also consists of an outer cortex of grey matter and an inner core of white matter. Its surface is also marked by many grooves. The cere-

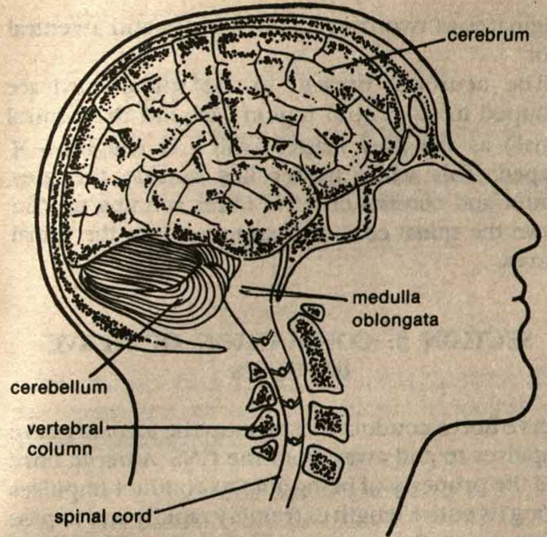


FIG. 24.6 Longitudinal section through human head, showing position and structure of brain

bellum has right and left lobes joined together by a bridge of white matter called **pons**. The **pons** has nerve fibres which pass up and down between the **mid-brain** above and the **medulla oblongata** below. The medulla oblongata lies below the pons and connects the brain with the spinal cord.

FUNCTIONS

The functions of the important parts of the brain are now described.

(i) The cerebrum: All parts of our body are connected, directly or indirectly, to the cerebrum [Fig. 24.7]. Information from all the receptor organs is received first by the sensory areas of the cerebrum. For this purpose, there are definite areas concerned with receiving and processing the sensations. The motor nerve impulses to the effector organs for responding to stimuli are also sent from the motor areas of the cerebrum. The cerebrum controls all the deliberate and voluntary muscular activities of the body. In addition, it also controls our thinking, reasoning, learning, memory, consciousness, and emotions.

Certain areas are supplied with nerve fibres from main sense centres of the brain. Their purpose is to correlate these centres so that information gained from several sense organs may be used to obtain a true picture of a given situation. These centres are known as **association centres**, which sort out, integrate, and store information.

(ii) The cerebellum: This part of the brain is concerned with maintaining the balance and coordination of muscular activities. It ensures coordination between various movements of the body.

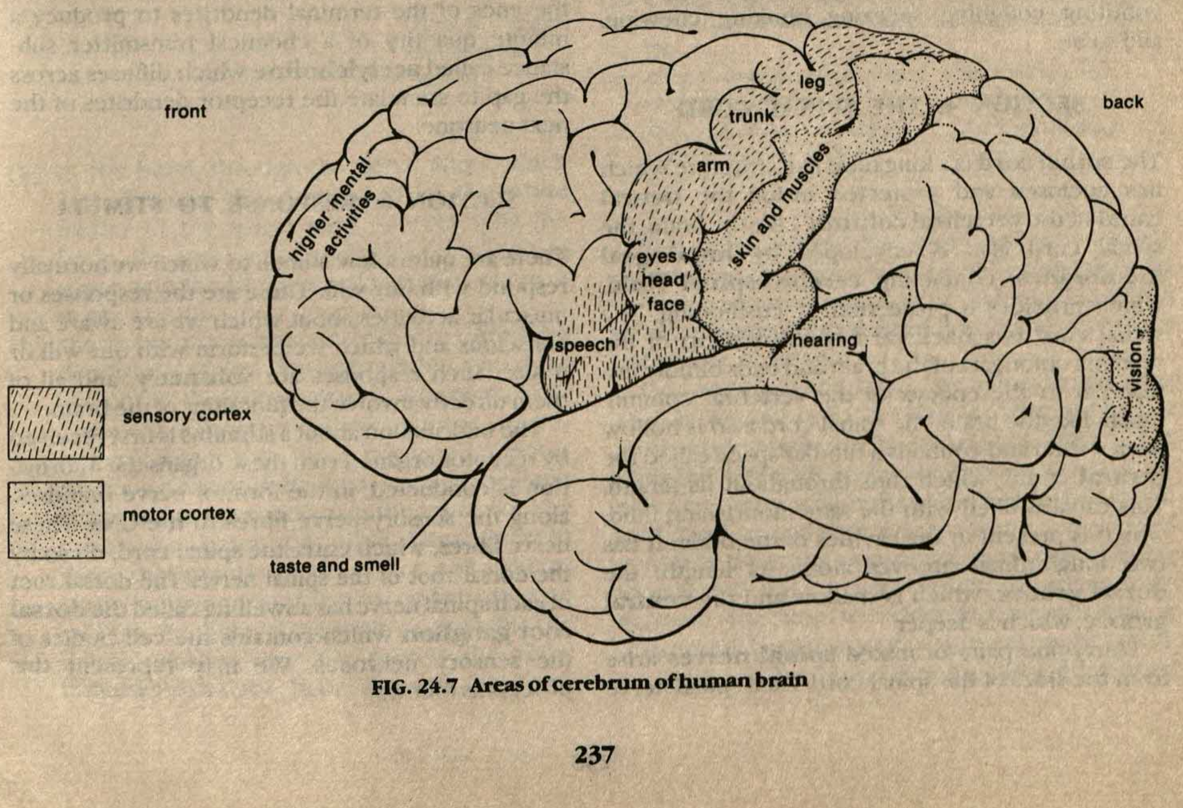


FIG. 24.7 Areas of cerebrum of human brain

For example, if you have to pick up a football from the ground, you would bend your body forward in response to an instruction from the cerebrum, and the cerebellum sends nerve impulses automatically to various parts of your body, enabling them to move in a way that would maintain a proper balance of the body. Complicated patterns of muscular activities involved in learning how to swim or play a musical instrument are controlled by the cerebrum in the beginning, but, later on, with adequate practice, the patterns of these activities come under the control of the cerebellum.

(iii) The mid-brain: It conveys impulses to and carries them away from the cerebral hemispheres.

In a small portion of the brain lying between the mid-brain and the cerebrum are present two very important structures: (a) **hypothalamus**, which contains centres controlling such functions as body temperature, osmoregulation, sleep and wakefulness and (b) the pituitary gland, which is an endocrine gland regulating a number of body activities.

(iv) The pons: This deals with impulses from the face. It carries impulses to and from the cerebral hemispheres and also to and from the cerebellum.

(v) The medulla oblongata: This is the seat of control of some of the involuntary and automatic activities of body such as the heart beat and breathing movements, swallowing, salivation, vomiting, coughing, sneezing, blinking, chewing, and so on.

SECTION 4: THE SPINAL CORD

The **spinal cord** is a long tube-like structure which lies enclosed and protected inside the **neural canal** of the **vertebral column**. Like the brain, the spinal cord also is enveloped by **meningeal membranes**, containing **cerebro-spinal fluid**, which provides it protection by cushioning. The spinal cord is a **backward continuation** of the medulla oblongata of the brain and ends blindly in a filament in the coccyx of the vertebral column. Again, like the brain, the spinal cord also is hollow from within and contains a tubular space called the **central canal**, which runs throughout its length. This canal is filled with the same nourishing fluid, which is present in the cavities of the brain. It has two longitudinal grooves along its length: the **dorsal groove**, which is shallow and the **ventral groove**, which is deeper.

Thirty-one pairs of mixed **spinal nerves** arise from the sides of the spinal cord. Each spinal nerve originates as two roots: a dorsal root and a ventral root.

The neurones present in the spinal cord are grouped in its central region (around the central canal) as the grey matter which is roughly—)(shaped. This white matter lies outside the grey matter and consists of nerve fibres running up and down the spinal cord or passing out into the spinal nerves.

SECTION 5: CONDUCTION OF NERVE IMPULSES

Nerve fibres conduct messages in the form of nerve impulses to and away from the CNS. A nerve fibre has the property of being able to conduct impulses along its entire length extremely rapidly and to pass them on to the next neurone in line. The nerve fibres can conduct the impulses in only one direction. From one neurone to the next one, the nerve impulses are passed on at junctions called **synapses**. A synapse is formed between the terminal dendrites of an axon and the receptor dendrites of the cell body of the next neurone. There is no protoplasmic connection between the two neurones at a synapse; instead, there is a gap, and the nerve impulses jump across this gap. When a nerve impulse reaches the end of a nerve fibre, it causes the ends of the terminal dendrites to produce a minute quantity of a chemical transmitter substance called **acetylcholine** which diffuses across the gap to stimulate the receptor dendrites of the next neurone.

SECTION 6: RESPONSE TO STIMULI

There are quite a few stimuli to which we normally respond with our will. These are the responses or muscular activities about which we are aware and conscious and which we perform with our will or desire. Such responses are **voluntary**, and all of them directly involve the functions of the brain.

The information about a stimulus is first received by receptor organs. From these organs the information is conducted, in the form of nerve impulses, along the sensory nerve fibres to the CNS. These nerve fibres, which enter the spinal cord, do so by the dorsal root of the spinal nerve. The dorsal root of each spinal nerve has a swelling called the **dorsal root ganglion** which contains the cell bodies of the sensory neurones. We may represent this process as follows:

Stimulus
↓
(Sensory cell in receptor organs)
↓
Dendron of the sensory neurone in the spinal nerve
↓
Cell body of the sensory neurone in the dorsal root ganglion
↓
Axon of the sensory neurone
↓
Spinal cord

The axon which brings the nerve impulse into the spinal cord may further conduct it along either of the following paths:

Axon of the sensory neurone

To the nerve fibres which ascend in the dorsal part of the white matter of the spinal cord to the brain.

or

From the brain along the nerve fibres which descend in the ventral part of the white matter in the spinal cord

To an intermediate neurone in the grey matter of the spinal cord
↓
Motor neurone in the grey matter of the spinal cord
↓
Axon
↓
Effector organs (muscles and glands)

(a) to the brain, through the nerve fibres which ascend along the dorsal part of the white matter of the spinal cord. On reaching the brain, the nerve impulse enables the brain to appreciate the stimulus and makes us aware of it; **or**

(b) the axon makes contact (synapse) with the dendrites of an **intermediate neurone** present in the grey matter of the spinal cord. The axon of the intermediate neurone, in turn, makes contact with the dendrites of a motor neurone present in the grey matter. The axon of the motor neurone leaves the spinal cord by way of the ventral root of the spinal nerve to carry the impulse to the concerned effector organ to bring about the necessary response without the help of the brain or the will. The motor neurone may also receive the nerve impulses from the brain through the nerve fibres which descend along the ventral part of the white matter of the spinal cord. The nerve impulses received from the brain are also conducted to the concerned effector organ by the axon of the motor neurone in order to enable the effector organs to act by an effort of the will.

SECTION 7: REFLEX ACTION

Reflex action is defined as a quick, spontaneous, mechanical, and involuntary action in response to a stimulus by an organ or a system of organs. Examples of reflex actions are given in Table 24.1.

TABLE 24.1 EXAMPLES OF REFLEX ACTION

	STIMULUS	RESPONSE (REFLEX ACTION)
1.	Dust particles or a small insect descend(s) on the surface of the eye.	The eyelid closes and the eye begins to water.
2.	Light intensity increases/ decreases.	The size of the pupil increases/decreases.
3.	Foreign particles irritate the inner lining of the nose, as in the case of the smell of powdered pepper or snuff.	Sneezing.
4.	Foreign particles irritate the inner lining of the throat.	Coughing.
5.	A sharp tap given to the tendon below the knee cap of a crossed leg.	The lower part of the leg jerks or kicks upward.
6.	The touch of a live electric wire suddenly (by the hand).	The hand is quickly withdrawn.
7.	The touch of a very hot object unexpectedly (by the hand).	The hand is quickly withdrawn.

In a reflex action, the impulse travels along a determined path known as the **reflex arc** to bring about a response. The reflex arc, in the reflex action of, say, withdrawing the hand quickly on touching a hot object, is as follows.

On touching a hot object unexpectedly, the heat or pain receptors in the skin are stimulated and send nerve impulses to the spinal cord. These nerve impulses travel along the dendron of the sensory neurone whose cell body is located in the dorsal root ganglion and then along its axon to the spinal cord [Fig. 24.8]. On reaching the grey matter in the spinal cord, the impulses pass to an intermediate neurone. The axon of the intermediate neurone, in turn, forms a synapse with a motor neurone whose axon carries the motor impulse along the ventral

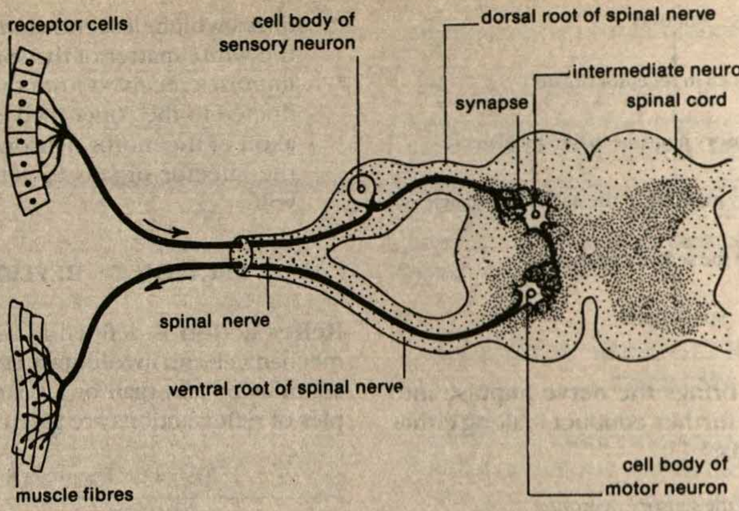

receptor cells
cell body of sensory neuron
dorsal root of spinal nerve
intermediate neuron
synapse
spinal cord
spinal nerve
ventral root of spinal nerve
cell body of motor neuron
muscle fibres

Fig. 24.8 Reflex are involving three neurones connected by synapses

root of the spinal cord to the muscles. These muscles contract and pull the hand away from the hot object. The whole process takes place instantaneously, and we are amazed at the speed. The action or response is, in fact, automatic and quite spontaneous, and we are invariably unconscious of it. This involuntary and spontaneous action helps in protecting our hand from damage due to heat. The quickness of the response is due to the short circuit, i.e., a direct connection (not through the brain) in the central nervous system between a sensory and motor neurone by way of an intermediate neurone. We may represent the entire action as follows:

Stimulus ⟶ Sensory cells of a receptor organ ⟶ Dendron of the sensory neurone along the dorsal root ⟶Cell body of a sensory neurone ⟶ Axon of the sensory neurone ⟶ INTERMEDIATE NEURONE IN THE SPINAL CORD ⟶ Axon of the intermediate neurone ⟶ Motor neurone ⟶ Axon of the motor neurone along the ventral root ⟶ Effector organ (muscles or glands)

Reflex actions do not have to be learnt; they are inborn. They take place in the same manner every time and are very difficult to suppress. For instance, when one tries to refrain from blinking while someone waves a hand in front of the eyes, one realises how difficult the task is.

In a voluntary action, the impulse usually originates from the CNS and is transmitted by a motor neurone to the effector neurone. There is no involvement of the intermediate neurone. A reflex action, on the other hand, has its origin outside the CNS and involves the intermediate neurone.

EXERCISES

SECTION 1

1. What does the nervous system in human beings consist of?
2. State the functions of the nervous system.
3. Define the following terms: (a) receptor organs and (b) effector organs.

SECTION 2

4. (a) What does nervous tissue consist of?
   (b) Name the two types of neurones and briefly describe their functions.
5. Describe, with the aid of a simple diagram, the structure of a sensory nerve cell and explain how it functions.

SECTIONS 3 AND 4

6. Draw and label a simple diagram of the human brain. With the aid of this diagram, describe the functions of each part of the brain.
7. (a) Describe the spinal cord and state how it is connected to the brain. How is it enclosed in the vertebral column?
   (b) What is the importance of the spinal cord and what are its functions?
8. What do you understand by the following terms: (a) nerve impulses; (b) synapse; (c) voluntary action;

(d) reflex action; (e) intermediate neurone; (f) reflex arc; (g) terminal dendrite; and (h) dorsal root ganglion?

SECTION 5, 6, AND 7

9. Briefly describe how nerve impulses are conducted.

10. Outline the process by which the brain responds to stimuli and describe the roles of the different organs involved.

11. What do you understand by 'reflex action'? Discuss giving suitable examples.

CHAPTER 25

The Sense Organs in Human Beings

One of the most important functions of our nervous system, as stated earlier, is to keep us informed about the changes in the surroundings so that we may react to these changes with the objective of ensuring our safety and survival. Certain parts of our body, such as the eyes, the ears, the skin, the tongue, and the lining of the nose, are specially developed organs sensitive to changes in our environment. These parts of the body are known as **receptors**, or **sense organs**, and any type of information from our surroundings which brings a receptor into action is called a **stimulus**. The reactions of living organisms to the stimuli which they receive are known as **responses** and the sum total of a living organism's responses constitutes its **behaviour**.

SECTION 1: THE RECEPTOR ORGANS OF TOUCH, TASTE, AND SMELL

THE SKIN

The functions of the skin have already been discussed (see Chapter 22). The skin forms a very important link with our surroundings. Located in the skin are the nerve endings which enable it to function as a sense organ. These nerve endings make us sensitive to a variety of different stimuli, giving rise to various sensations, such as heat, cold, physical contact, pain, and pleasure. When these stimuli activate the nerve endings in the skin, nerve impulses are sent to the brain or the spinal cord, where they are recorded and the sensations are felt accordingly.

THE TONGUE

The sensation of **taste** is felt in the mouth by means of hairy sensory cells, which are some of the epithelial cells of the tongue. The cells are specialised to receive the stimulus and transmit it further to the sensory neurones whose receptor dendrites are in contact with these sensory cells located on the tongue. The receptors are situated on the upper surface of the tongue, on projections called **taste buds** [Fig. 25.1]. They are connected to the taste

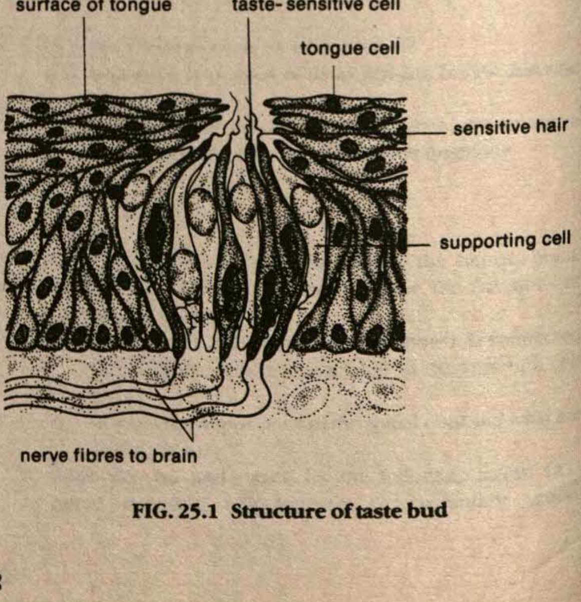


FIG. 25.1 Structure of taste bud

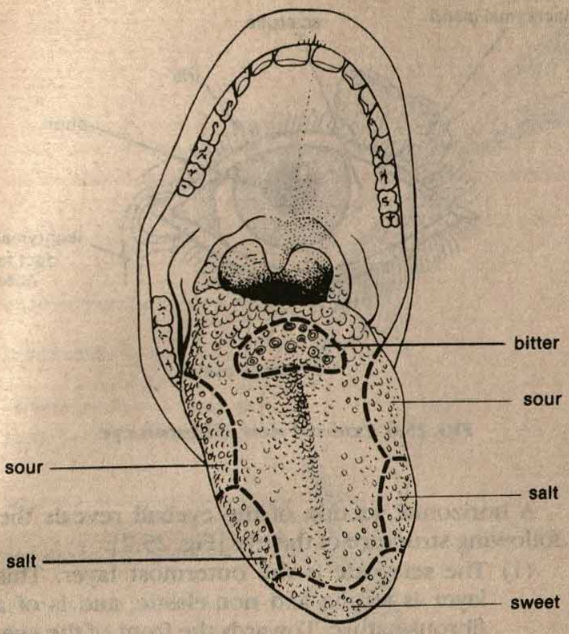


FIG. 25.2 **Taste areas of human tongue**

centres of the brain by nerves. Taste buds respond to various sensations: sweetness, bitterness, sourness, and saltiness. Different groups of receptors on the tongue detect different sensations [Fig. 25.2]: sweetness and saltiness are detected at the **tip** of the tongue; sourness is detected at the **sides**; and bitterness at the **back.** This can be ascertained by touching these different areas with glass rods previously dipped in solutions of sugar, salt, quinine, and lime juice. The chemicals giving rise to the sensation of taste must be in solution; only then can they stimulate the receptors which send nerve impulses to the brain. Taste receptors on the tongue enable us to determine whether or not we are eating suitable food.

THE NOSE

In the **mucous membrane** lining the top of the nasal cavity, there are olfactory cells [Fig. 25.3]— specialised bipolar neurones. Sensory hairs (modified receptor dendrites) of these olfactory cells extend into the mucous film spread over the mucous membrane, and these are sensitive to smells [Fig. 25.4]. From the olfactory cells, nerve fibres pass into the brain. These cells are stimulated by chemical substances which arrive in the air breathed in through the nose and dissolved in the **mucous** covering the mucous membrane of the nasal cavity. Why does our sense of smell seem to disappear on a very hot summer day? This happens because the heat dries up the mucus and, as a result, the chemical substances cannot dissolve in order to stimulate the receptors. Also, when we suffer from a cold, we cannot detect smells because of the excessive amount of mucus produced, which prevents the chemical substances from reaching the sensory cells and stimulating them.

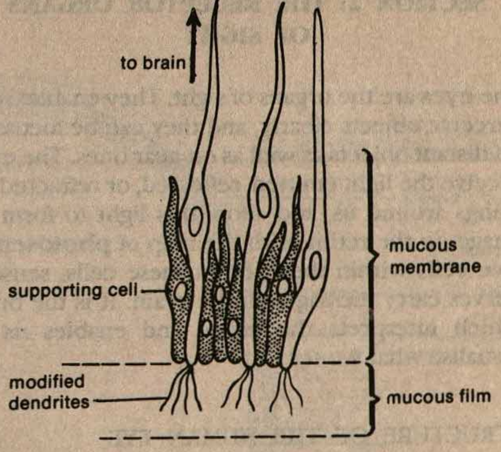


FIG. 25.3 **Olfactory cells**

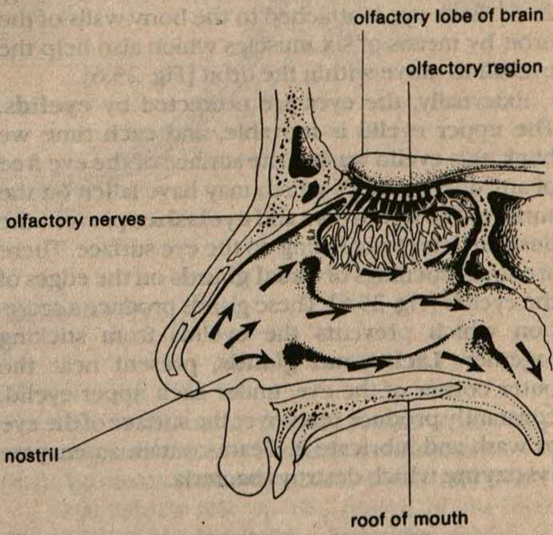


FIG. 25.4 **Longitudinal section of human nose, with arrows showing path of air during inhalation**

SECTION 2: THE RECEPTOR ORGANS OF SIGHT

The **eyes** are the organs of sight. They enable us to perceive objects clearly, and they can be focussed on distant objects as well as on near ones. The eyes receive the light emitted, reflected, or refracted by things around us, and allow this light to form an image on the retina with the help of **photosensitive** cells within them. From these cells, sensory nerves carry messages to the brain. It is the brain which interprets the image and enables us to visualise what we see.

STRUCTURE OF THE HUMAN EYE

Each eye is a spherical organ lodged in a deep socket in the skull, which is called the **orbit** [Fig. 25.5]. Each eye is attached to the bony walls of the orbit by means of six muscles which also help the eyeball to move within the orbit [Fig. 25.6].

Externally, the eyes are protected by **eyelids**. The upper eyelid is movable, and each time we blink, this eyelid washes the surface of the eye free of any dust particles which may have fallen on the surface. The **eyebrows** and **eyelashes** prevent the dust particles from falling on the eye surface. There are small openings of **tarsal glands** on the edges of the eyelids [Fig. 25.6]. These glands produce a secretion which prevents the eyelids from sticking together. **Lachrymal glands**, present near the outer corner of the eye, under each upper eyelid, constantly produce tears over the surface of the eye to wash and lubricate it. Tears contain an enzyme **lysozyme** which destroys bacteria.

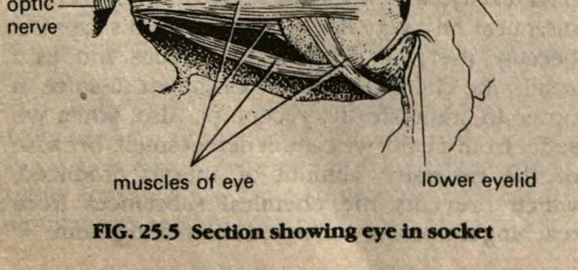


FIG. 25.5 Section showing eye in socket

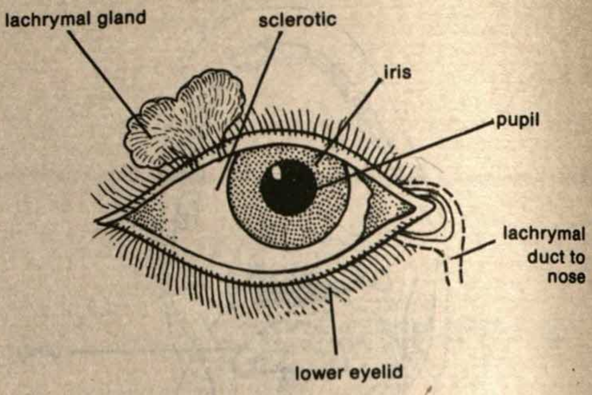


FIG. 25.6 External view of human eye

A horizontal section of the eyeball reveals the following structure of the eye [Fig. 25.7]:

(i) The **sclerotic** is the outermost layer. This layer is strong and non-elastic, and is of a fibrous nature. Towards the front of the eye, the sclerotic is modified to a slight bulge, which is transparent and is called the **cornea**.

(ii) The cornea, being transparent, permits light to pass through. Since the cornea is a curved surface, the light is refracted and the rays begin to converge.

(iii) The **conjunctiva** is a thin and transparent layer of cells which lines the eyelids internally. It protects the cornea.

(iv) The **choroid** lies within the sclerotic. It is richly supplied with blood vessels which bring food and oxygen to the eye. At the front of the eye, the choroid forms a flat, circular, and opaque disc called the **iris**. At the centre of the iris is an entrance, i.e., the **pupil**, which admits light into the eye to form an image on another layer called the **retina**. The colour of the eyes is due to the presence of pigments in the iris. The iris contains two types of muscle fibres—circular and radial. Both these muscle fibres are involuntary. When the light becomes very bright, the circular muscles contract to make the pupil smaller. On the other hand, when the light is dim, the radial muscles contract to make the pupil larger.

(v) The **retina** is a thin, transparent layer over the inner surface of the choroid. It is a light-sensitive layer consisting of specialised neurones called **rods and cones**. Rods are more sensitive and they are stimulated by

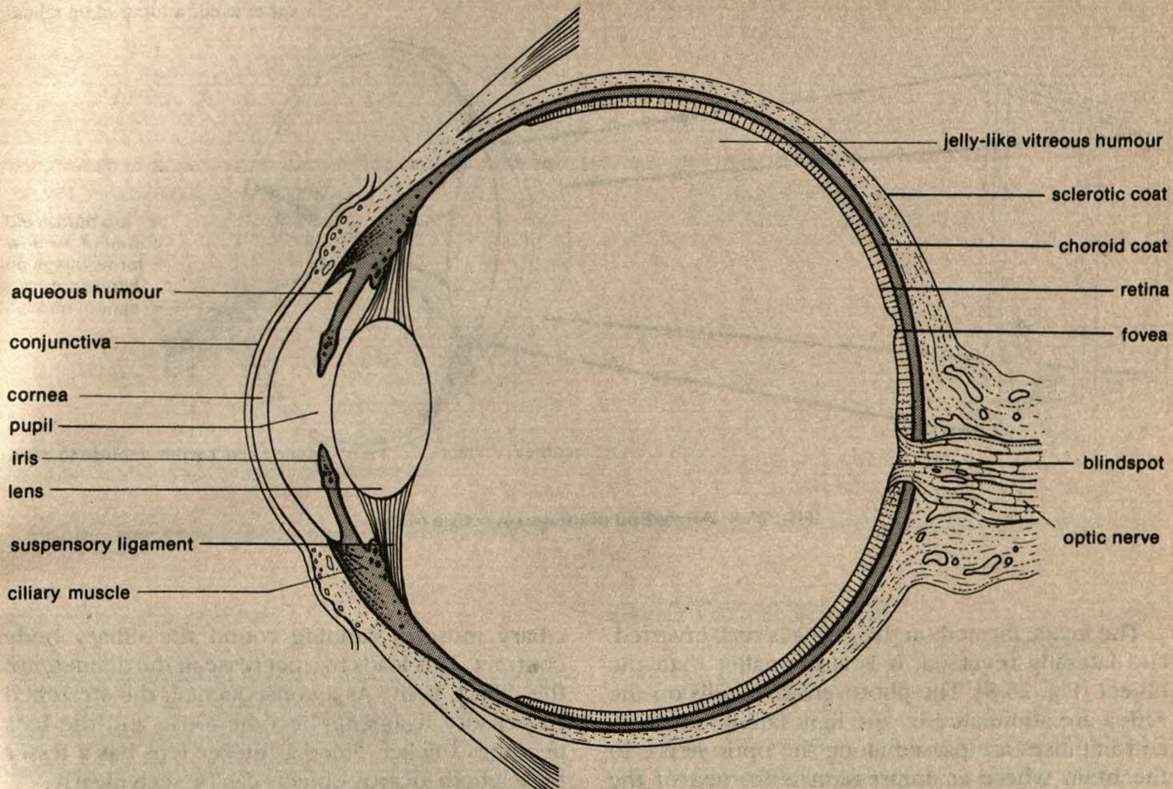


FIG. 25.7 Section through human eye

dim light. They are capable of distinguishing black, white, and shades of grey, whereas cones are stimulated by bright light only in order to differentiate one colour from another. The nerve fibres from these neurones pass across the front of the retina and all of them leave at one point to form the **optic nerve** which carries the stimuli to the brain. This point where the nerve fibres converge to form the optic nerve is called the **blind spot**. The blind spot is completely insensitive because it does not contain any receptor cells. If part of an image falls on the blind spot, no image is recorded in the brain. It is the **yellow spot** which is the most sensitive region of the retina. It has the maximum concentration of sensory cells, and, therefore, gives the most accurate image of the object. This region contains cones only.

(vi) **Aqueous humour** is a transparent, jelly-like material which fills up the region of the eye in front of the crystalline lens. This region is called the **aqueous chamber**.

(vii) **Vitreous humour** also is a jelly-like material which fills up the region of the eye behind the crystalline lens. This region is called the **vitreous chamber**.

(viii) The **crystalline lens** is made of transparent living cells which are surrounded by an elastic capsule. The lens is held in position by the fibres of the **suspensory ligament** which arise from its edge and are attached to the **ciliary body**. Like the cornea, conjunctiva, aqueous humour, and vitreous humour, the lens also refracts the light for producing an image on the retina.

(ix) The **ciliary body** is the thickened rim of the choroid in the region around the lens. It contains the **ciliary muscles**, which contract and relax to change the shape of the lens in order to focus the eye on both distant and near objects.

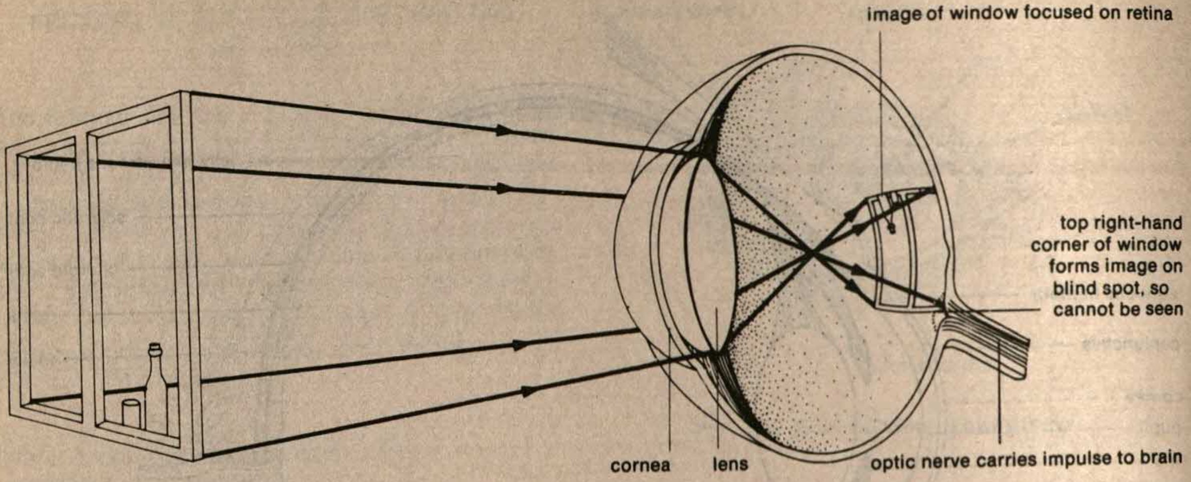


image of window focused on retina
top right-hand corner of window forms image on blind spot, so cannot be seen
cornea
lens
optic nerve carries impulse to brain

FIG. 25.8 Formation of image on retina of eye

The image formed on the retina is real, inverted, and laterally reversed. It is also smaller than the object [Fig. 25.8]. The photosensitive cells on the retina are stimulated by the light falling on them, and impulses are passed along the optic nerve to the brain where an impression is formed of the nature, size, colour, and distance of the object. When we look at an object, which is either nearby or at a distance, the view seen by the right eye is slightly different from that seen by the left eye. Consequently, two slightly different images of the same object are recorded in the brain. However, the specific visual centre in the brain fuses the two images to give a three-dimensional impression, which enables us to appreciate the depth, width, height, distance, etc., of the object. The brain also reverses the inverted and laterally reversed images formed on the retina, so that we see the object the correct way up and also in the correct perspective.

ACCOMMODATION

This is the ability of the lens to alter its shape and thus accurately focus both near and distant objects on the retina. This is achieved by adjusting the thickness of the crystalline lens. When the eye is at rest, the ciliary muscles in the ciliary body are relaxed; the suspensory ligaments are stretched; and the lens is thin. Since a thin lens has a greater focal length, the eye at rest is adapted to see far-off objects. When a nearby object has to be seen, the ciliary muscles running round the ciliary body contract. This leads to a decrease in the diameter of the ciliary body. As a consequence, the stretched suspensory ligaments become loose and the lens becomes thicker. Since a thicker lens has a lesser focal length, nearby objects can be seen clearly.

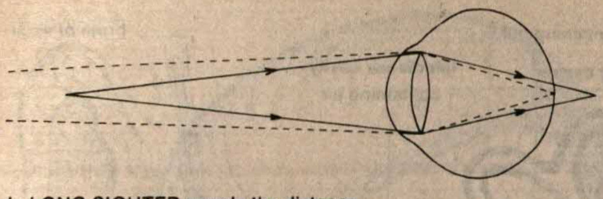
DEFECTS AND DISEASES OF THE EYE

There are several defects and diseases of the eye; some of the common ones are as follows.

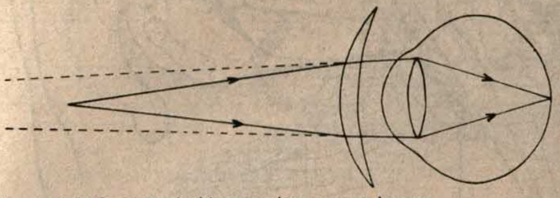
LONG-SIGHTEDNESS OR HYPERMETROPIA

In this condition, a person can see only **distant** objects clearly; light from a nearby object is brought to focus **behind** the retina since the converging power of the lens is not high enough, and thus the image of this object is blurred [Fig. 25.9]. This defect arises when the lenses of the eyes have lost some of their elasticity and cannot alter their shape to become more biconvex for focussing nearby objects on the retina. This defect may also be due to small eyeballs, in which case, the distance between the lens and the retina is too small to allow accurate focussing.

Long-sightedness can be corrected by wearing spectacles with **converging (convex) lenses**, which bend the rays of light to focus exactly on the retina.

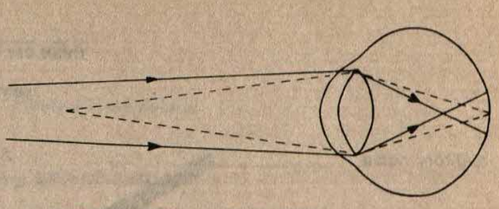


In LONG SIGHTED people the distance from cornea to retina is too short

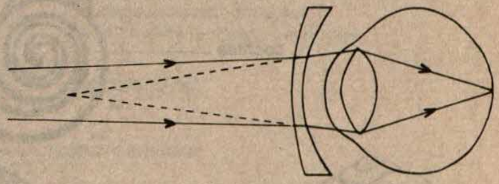


Long sight is corrected by wearing convex lenses

FIG. 25.9 Occurrence and correction of hypermetropia



In SHORT SIGHTED people the distance from cornea to retina is too long



Short sight is corrected by wearing concave lenses

FIG. 25.10 Occurrence and correction of myopia

Short-sightedness or Myopia

In this condition, the person can see **near** objects only; light from distant objects is brought to focus before the retina since the converging power of the lens is too great and thus the image of a distant object is blurred [Fig. 25.10]. This is because the lenses, due to loss of elasticity, fail to alter their shape and become thinner, thus becoming unable to focus distant objects on the retina. This defect may also be due to large eyeballs, in which case the distance between the lens and the retina is too great to allow accurate focussing.

Short-sightedness can be corrected by wearing spectacles with **diverging (concave) lenses** with a greater focal length for focussing the light exactly on the retina.

Astigmatism

This is a defect in which horizontal and vertical lines are not seen with equal clarity. Astigmatism is caused by the unequal curvature of the cornea and can be corrected by the use of **cylindrical lenses.**

SECTION 3: THE RECEPTOR ORGANS OF SOUND

The **ears** are the receptor organs of sound. A major portion of the ears lies enbedded (and protected) in the skull bones. An ear is divisible into three parts: the **outer ear**, the **middle ear**, and the **inner ear.**

STRUCTURE OF THE EAR

The Outer Ear

The outer ear consists of the **pinna** and the **outer ear tube**. The pinna is a funnel-like flap of cartilage and skin which serves to direct the sound waves into the outer ear tube. This tube leads inwards towards the middle ear from which it is separated by the **eardrum** or **tympanic membrane**. The ear drum is a tightly stretched membrane made up of many fibres of different lengths, which allow it to vibrate under the influence of sound waves of different frequencies. The walls of the outer ear contain gland cells which secrete **wax**. This wax helps to keep the eardrum pliable. Finally, the hairs present in the outer ear tube help to keep out dust particles and small insects.

The Middle Ear

This is an air-filled cavity which lies just beyond the eardrum and is surrounded by bone. It is separated from the inner ear cavity by an oval window and a round window. Both the windows have membranes stretched across them. In the cavity of the middle ear are three small bones (or **ossicles**) known as **hammer (malleus)**, **anvil (incus)**, and **stirrup (stapes)**, all held in position by muscles. Malleus is attached to the eardrum whose vibrations are transmitted through these three bones to the membrane across the **oval window**. These small bones act as

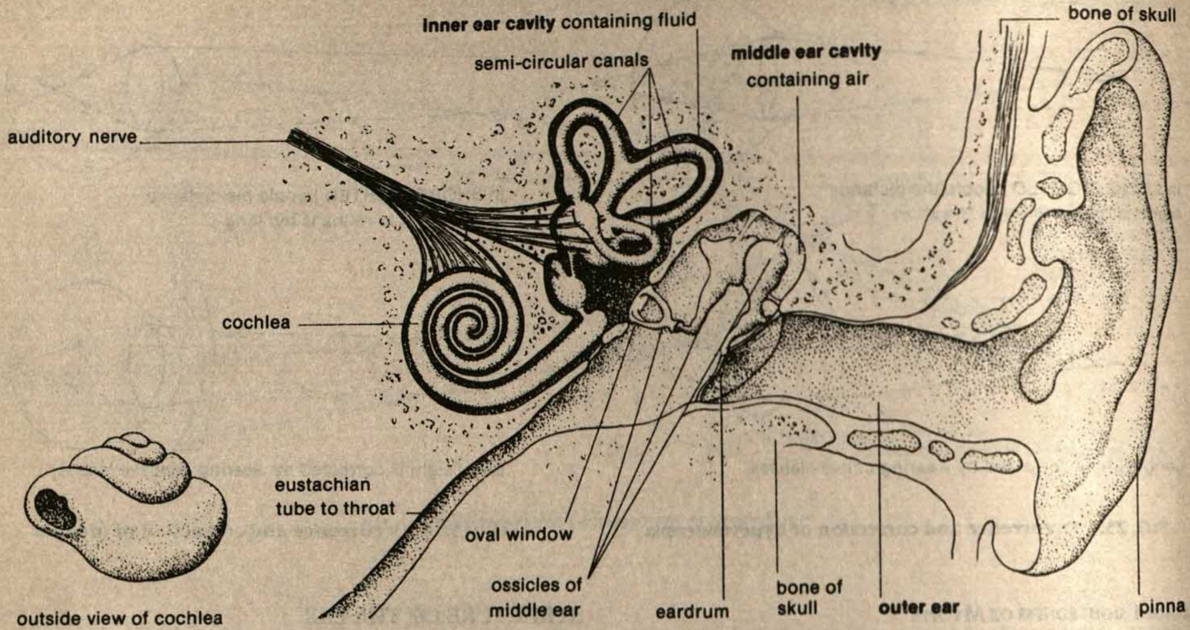


Fig. 25.11 Section through human ear, showing structure

levers and also serve to increase the power (magnitude) of the vibrations.

The middle ear cavity communicates with the **pharynx** by means of the **eustachian tube**. This connection ensures that the pressure on both sides of the ear drum is the same, being equal to the atmospheric air pressure. This regulation of pressure is required both for the maintenance and for the proper functioning of the tympanic membrane.

The Inner Ear

The **inner ear** contains a **membranous labyrinth**, which consists of a spirally coiled tube, **cochlea**, a **vestibule**, and **three semicircular canals**. The cochlea consists of three fluid-filled parallel canals: (1) the vestibular canal (connecting with the oval window) containing fluid **perilymph**; (2) the **cochlear canal** filled with fluid **endolymph**; and (3) the **tympanic canal** (connecting with the round window) filled with **perilymph**. These canals are separated from each other by membranes, namely, **Reissner's membrane** between vestibular and cochlear canals, and the **basilar membrane** between cochlear and tympanic canals. The cochlear canal contains a membranous shelf—**tectorial membrane**— which projects parallel to the basilar membrane for the full length of the cochlear canal. Sensory cells which form the **organ of Corti** arise from the basilar membrane [Fig. 25.12]. These sensory cells have fine sensitive hairs which just reach the tectorial membrane. The organ of Corti is supplied with nerve fibres of the **auditory nerve**.

THE MECHANISM OF HEARING

The following sequence of events enables us to hear a sound: Sound waves in the air enter the **pinna**. These sound waves pass down the **outer ear tube** and cause the **eardrum** to vibrate. The vibrations of the eardrum are amplified and transmitted by the three small ear bones across the middle ear cavity to the delicate membrane stretched across the **oval window**. The membrane across the oval window displaces the perilymph in the vestibular canal, which, in turn, causes movement of Reissner's membrane. This displaces the endolymph in the cochlear canal and moves the basilar membrane, thus leading to the displacement of the perilymph in the vestibular canal. Movement of the basilar membrane disturbs the sensory cells of the organ of Corti. The hairs of these sensory cells,

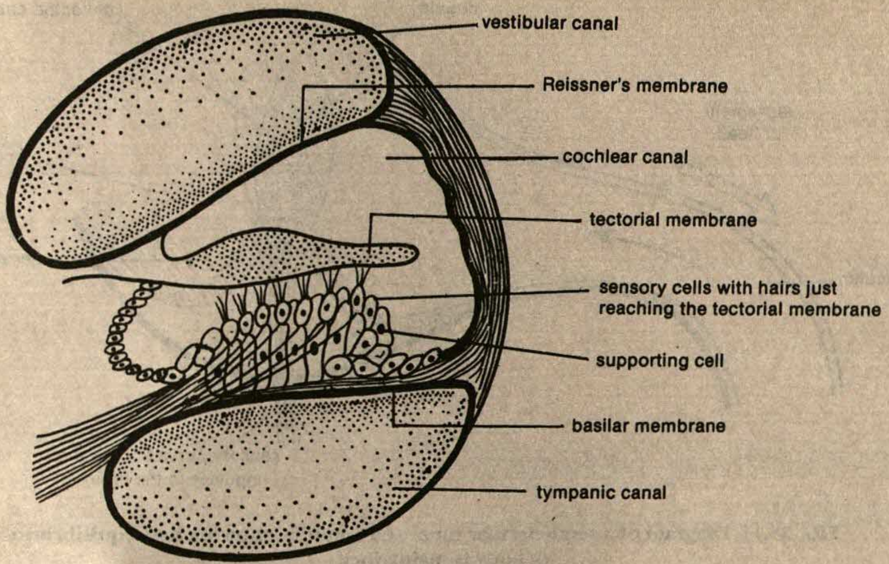


FIG. 25.12 Transverse section of organ of Corti

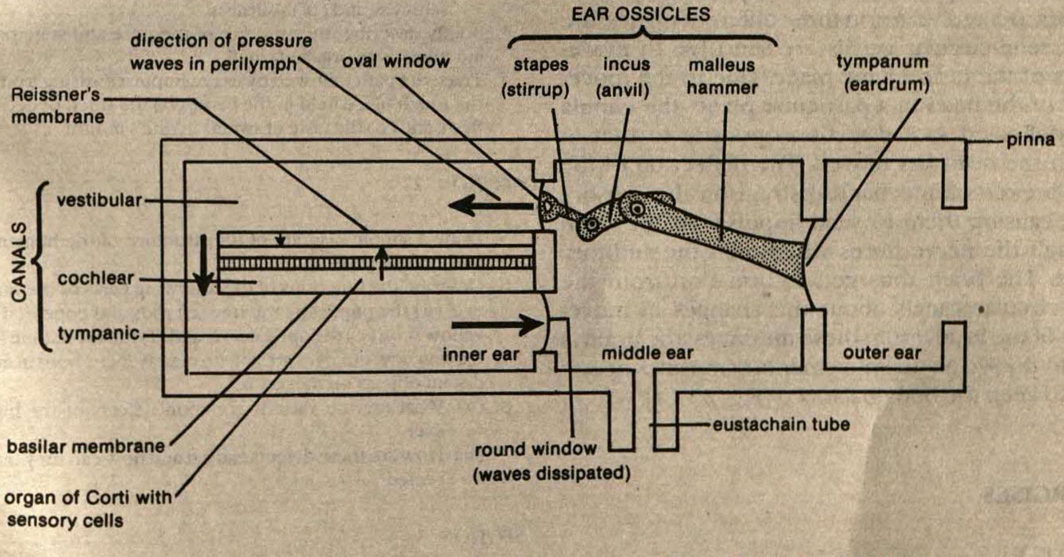


FIG. 25.13 Diagrammatic representation of the course of sound vibrations in the ear

which just touch the tectorial membrane when at rest, are subjected to stresses which are then transmitted as nerve impulses to the brain with the help of the nerve fibres of the auditory nerve. These nerve impulses are interpreted in the form of sounds in the brain. (See Fig. 25.13.)

THE MECHANISM OF BODY BALANCE

The three semi-circular canals (mentioned earlier) are arranged in three planes at right angles to each other in the inner ear. Each canal has a swelling called the **ampulla** at one of its ends. Each ampulla

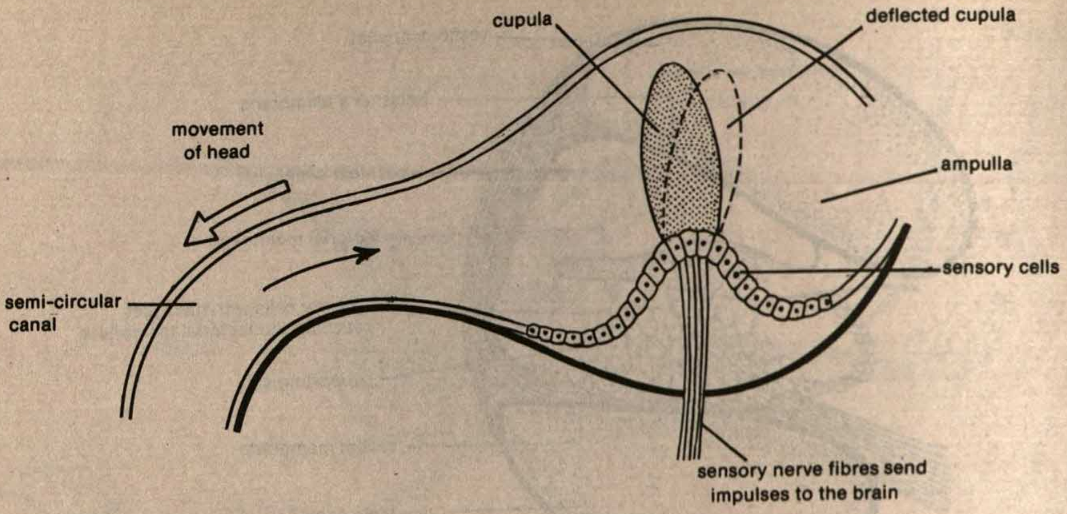


FIG. 25.14 Diagram of a semi-circular canal and ampulla showing how equilibrium of body is maintained

contains **sensory cells** whose hairs are embedded in a dome-shaped gelatinous cup known as the **cupula**. Being situated in three different planes, the three semi-circular canals are sensitive to movements of the head in any plane. Due to the movement of the head in a particular plane, the cupula gets deflected in a direction opposite to that in which the head has moved. The deflection of the cupula exerts a mechanical strain on the sensory cells, causing them to send impulses to the brain through the nerve fibres which join the auditory nerve. The brain thus gets information from the semi-circular canals about the changes in movement of the head. From these messages, the brain is able to decide on the movements of muscles necessary to keep the body balanced [Fig. 25.14].

EXERCISES

SECTION 1

1. How does the skin function as a receptor organ?
2. (a) What are taste buds?
   (b) Draw a simple diagram of the human tongue and mark on it the areas which are particularly sensitive to the following tastes: (i) sweetness; (ii) bitterness; (iii) saltiness; and (iv) sourness.
3. Briefly describe the structure of the nose and state how it functions as an organ of smell.
4. Trace the path followed by nerve impulses arising from: (a) the touch of ice held in the hand; (b) the smell of decaying flesh; and (c) the taste of sweets in one's mouth.

SECTION 2

5. Draw a simple diagram of the structure of the human eye and label its parts.
6. Describe the functions of the following parts of the human eye: (a) the pupil; (b) the iris; (c) rods and cones; (d) the yellow spot; (e) the optic nerve; and (f) the crystalline lens.
7. Explain how our eyes are able to clearly focus both near and distant objects on the retina.
8. (a) What are the various common defects of the human eye?
   (b) How are these defects caused and how can they be corrected?

SECTION 3

9. Briefly describe the mechanism of hearing in human beings.
10. What are the functions of the following: (a) wax in the outer ear; (b) eustachian tube; (c) semi-circular canals; (d) cochlea; and (e) ear ossicles?

CHAPTER 26

Chemical Coordination in the Human Body

The role of the nervous system in the coordination of the activities and functions of the body has already been discussed. However, the nervous system is not the only means by which coordination is achieved.

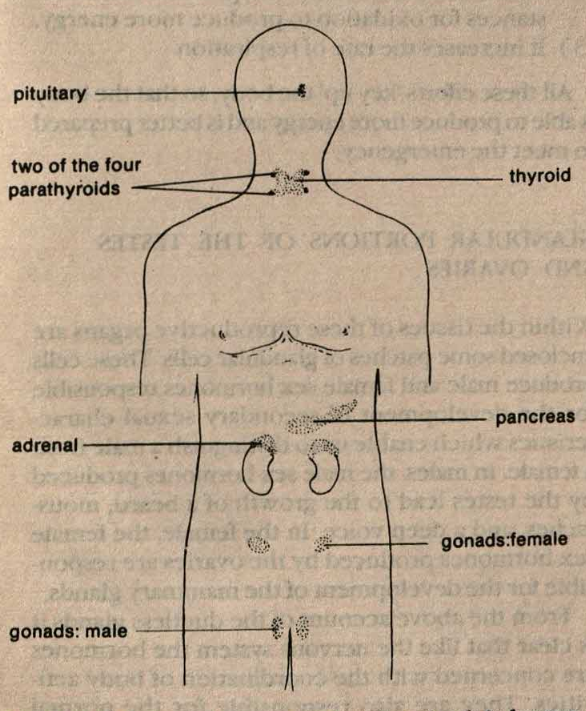


FIG. 26.1 Position of important ductless glands in human body

The functioning of the body, and to some extent its behaviour, may be influenced by the secretions of certain glands called the **endocrine glands** or **ductless glands**. The secretions of these glands are known as **hormones** or **autocoids**. Hormones are not carried away from the glands by means of any tubes or ducts (unlike as in the case of the digestive glands, e.g., the liver produces bile which is carried to the duodenum by the bile duct). Hormones diffuse directly into the blood flowing in the capillaries through these glands. Hormones are chemical substances which dissolve in the blood and which reach various body cells by diffusing into them from the blood vessels around them. Hormones are effective in very small quantities. They circulate with the blood throughout the body but they affect and influence the functioning of only specific organs.

The main endocrine glands are [Fig. 26.1]:

(1) The pituitary gland.
(2) The thyroid gland.
(3) The islets of Langerhans in the pancreas.
(4) The lining of the small intestine.
(5) The adrenal glands.
(6) The glandular portions of the testes and ovaries.

THE PITUITARY GLAND

This gland is situated on the under side of the brain. It is sometimes called the **master gland** of the endocrine system as one of its chief functions is to regulate the activities of the other ductless glands. It produces a number of hormones which influence the metabolic processes of the body. Overactivity of this gland leads to **gigantism** while underactivity results in **dwarfism**.

THE THYROID GLAND

This gland is a two-lobed gland and lies in front of the trachea, at the base of the larynx. It produces a hormone called **thyroxin**, which contains iodine and is necessary for the normal growth and development of the body. If there is a deficiency of iodine in the diet, this gland enlarges and leads to protruding eyes and a swollen condition of the neck, known as **goitre**. If, due to underactivity of the gland, thyroxin is deficient in a child, the result is **cretinism**, i.e., extremely poor physical and mental development. In adults, deficiency causes **myxoedema**, characterised by slow mental and physical activities and a tendency to put on weight.

THE ISLETS OF LANGERHANS IN THE PANCREAS

While most of the cells of the pancreas are concerned with the production of pancreatic juice, there are some patches or islets of cells which produce a hormone called **insulin**. This hormone keeps the glucose content of the blood down to its normal value of 150 mg per 100 cm^3 of blood. This regulation of the sugar content of the blood is achieved when:

(1) The insulin stimulates the cells of the liver to convert the excess of glucose into glycogen, which is stored in the liver and the muscles.
(2) The insulin increases the ability of the muscles to oxidise glucose to produce energy.

Deficiency of insulin leads to a disease called **diabetes**, in which sugar is passed in the urine. This happens because in the absence of insulin the cells of the liver are not able to convert excess of glucose in the blood into glycogen. When the blood containing an excess of glucose reaches the kidneys, the urinary tubules take it out of the blood and excrete it with urine.

THE LINING OF THE SMALL INTESTINE

When acidic food from the stomach enters the duodenum, it stimulates certain cells in the lining of the duodenum to secrete a hormone called **secretin**. When secretin reaches the pancreas through the blood stream, the pancreas releases pancreatic juice in order to digest the food.

THE ADRENAL GLAND

There are two adrenal glands, each one located at the upper end of each kidney. The central region of this gland secretes a hormone called **adrenalin**. During normal conditions of rest, there is little adrenalin in the blood, but under conditions which demand greater effort or when activated by excitement, fright, or anger, the production of adrenalin is greatly increased. This hormone affects our body to meet such emergencies in the following ways:

(1) It produces an increase in the rate of heart beat and raises the glucose content in the blood, so that the muscles receive more glucose and oxygen to produce more energy needed during an emergency.
(2) It causes the constriction of blood capillaries in the alimentary canal and skin, and dilation of those in muscles, which thus receive more blood and hence more oxygen and food substances for oxidation to produce more energy.
(3) It increases the rate of respiration.

All these efforts 'key up' the body, so that the body is able to produce more energy and is better prepared to meet the emergency.

GLANDULAR PORTIONS OF THE TESTES AND OVARIES

Within the tissues of these reproductive organs are enclosed some patches of glandular cells. These cells produce male and female sex hormones responsible for the development of secondary sexual characteristics which enable us to distinguish a male from a female. In males, the male sex hormones produced by the testes lead to the growth of a beard, moustaches, and a deep voice. In the female, the female sex hormones produced by the ovaries are responsible for the development of the mammary glands.

From the above account of the ductless glands it is clear that like the nervous system the hormones are concerned with the coordination of body activities. They are also responsible for the normal growth and development of a healthy human body.

EXERCISES

1. What are the endocrine glands and how do they differ from other glands such as the salivary glands, liver, and pancreas?
2. List the main endocrine glands and state their positions in the human body.
3. State the functions of the following: (a) the thyroid gland; (b) the pituitary gland; and (c) the adrenal gland.
4. Why are the testes and the ovaries regarded as ductless glands?
5. (a) What are hormones and what is their role in the working of the human body?
   (b) Make a table showing where the following hormones are produced in the human body, and how their excess and their deficiency affect normal functioning: (i) thyroxin; (ii) insulin; (iii) secretin; and (iv) adrenalin.

CHAPTER 27

Human Reproduction

The method of reproduction in all the higher animals is **sexual reproduction** because it involves two parents and the union or fusing together of a male reproductive cell (the **sperm**) and a female reproductive cell (the **ovum** or the **egg**). The reproductive cells are also called male or female **gametes** and are produced in the body of the male or female parents, respectively. However, these gametes are not produced until the age of sexual maturity (**puberty**) is attained, i.e., between 12 and 17 years of age in human beings.

The fusing together of the male and female gametes is known as **fertilisation**, which takes place in the female reproductive organs and leads to the formation of a **zygote**, from which a new individual can develop.

MALE REPRODUCTIVE ORGANS

The male gametes or sperms are produced by two glands called the **testes**, which are present in a special sac called the **scrotum** [Fig. 27.1]. From the testes the sperms reach the **epididymis**, which is a coiled tube about 6 metres long on the outside of each testis. Each epididymis in turn leads to a **sperm duct**, one from each testis. The two sperm ducts open into the top of the **urethra**, just after it leaves the urinary bladder. The urethra, at different times, carries both urine and sperms. The urethra is a narrow tube and runs through the penis to the outside. It consists of connective tissue with large blood vessels. Associated with the male reproductive

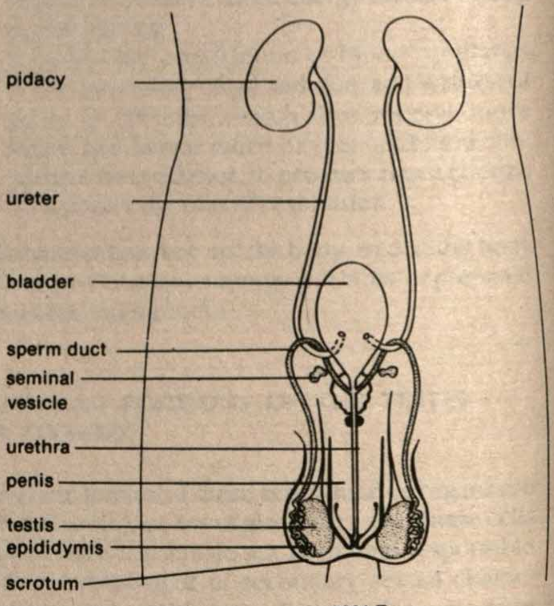


FIG. 27.1 Human male reproductive organs

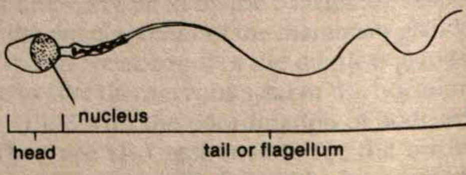


FIG. 27.2 Human sperm: front and side view (magnified 1250 times)

organs are some glands, namely, the **prostate gland** and **seminal vesicles** which produce secretions necessary for sperms. Figure 27.2 shows a human sperm magnified 1250 times.

FEMALE REPRODUCTIVE ORGANS

The eggs or female gametes, called **ova** [Fig. 27.3], are produced by two glands called **ovaries** [Fig. 27.4]. Ovaries lie at the back of the abdomen, below the kidneys. The eggs produced in the ovaries are received by the two expanded funnel-like openings of the **oviducts**, one on each side. The oviducts open into a wide thick-walled muscular chamber called the **uterus** or womb. The uterus communicates with the outside through a muscular passage called the **vagina**. The **cervix** is a ring of muscles of the lower end of the uterus, where it joins the vagina.

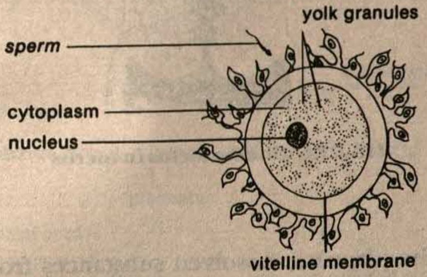


FIG. 27.3 Human ovum (magnified 100 times)

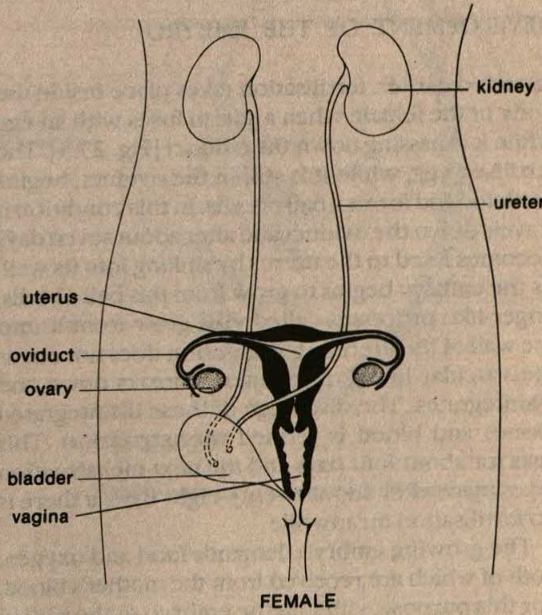


FIG. 27.4 Human female reproductive organs

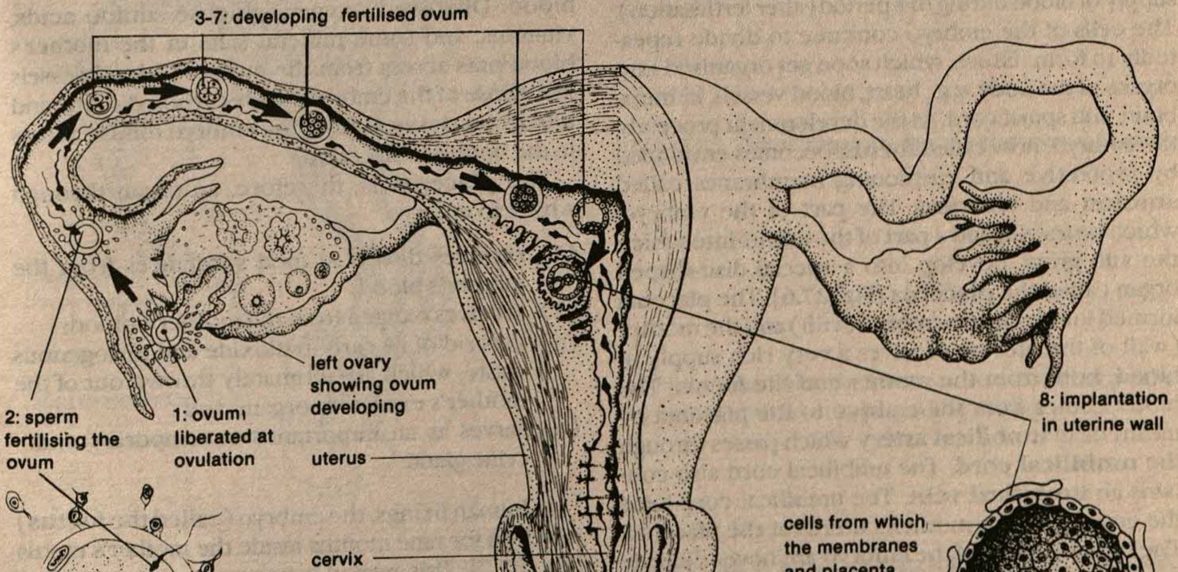


FIG. 27.5 Fertilisation and subsequent development in human being shown in eight successive stages

The urethra from the urinary bladder opens to the outside by a separate aperture which lies close to the opening of the vagina at the **vulva**.

DEVELOPMENT OF THE EMBYRO

As stated earlier, fertilisation takes place inside the body of the female when a sperm fuses with an egg while it is passing down the oviduct [Fig. 27.5]. The fertilised egg, while it is still in the oviduct, begins to divide and forms a ball of cells. In this condition it travels down the oviduct and after about seven days becomes fixed to the uterus by sinking into its wall. As the embryo begins to grow from this ball of cells, finger-like processes called **villi** grow from it into the wall of the uterus. If fertilisation does not occur the vascular lining of the uterus breaks down and disintegrates. The discharge of these disintegrated tissues and blood is termed **menstruation**. This lasts for about four days and the next menstruation takes place after about twenty-eight days, if there is no fertilisation meanwhile.

The growing embryo demands food and oxygen, both of which are received from the mother's blood. For this purpose, villi join the embryo to the wall of the uterus which thickens and develops a very rich supply of blood during this period (after fertilisation). The cells of the embryo continue to divide repeatedly to form tissues, which soon get organised into organs of the body, e.g., heart, blood vessels, kidneys, brain, and spinal cord. As the development proceeds, the embryo, now called **foetus**, becomes enveloped by protective and cushioning membranes called **amnion** and **chorion**. The part of the embryo, which bears villi and a part of the uterus into which the villi grow, develop into a special disc-shaped organ called the **placenta** [Fig. 27.6]. The placenta formed jointly by the embryo (villi) and the mother (wall of the uterus) receives a very rich supply of blood, both from the mother and the foetus. The blood comes from the embryo to the placenta by means of an **umbilical artery** which passes through the **umbilical cord**. The umbilical cord also contains an **umbilical vein**. The umbilical cord joins the embryo to the mother's uterus at the placenta. The blood vessels of the embryo are never directly connected to the mother's blood vessels in the wall of the uterus. If this did occur, the pressure of the mother's blood would burst the delicate blood vessels which are being formed in the embryo and also many chemical substances in the mother's blood could be harmful or toxic to the embryo.

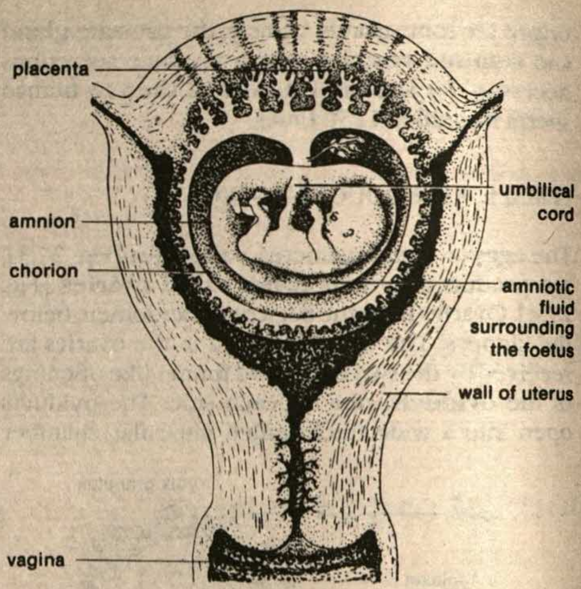


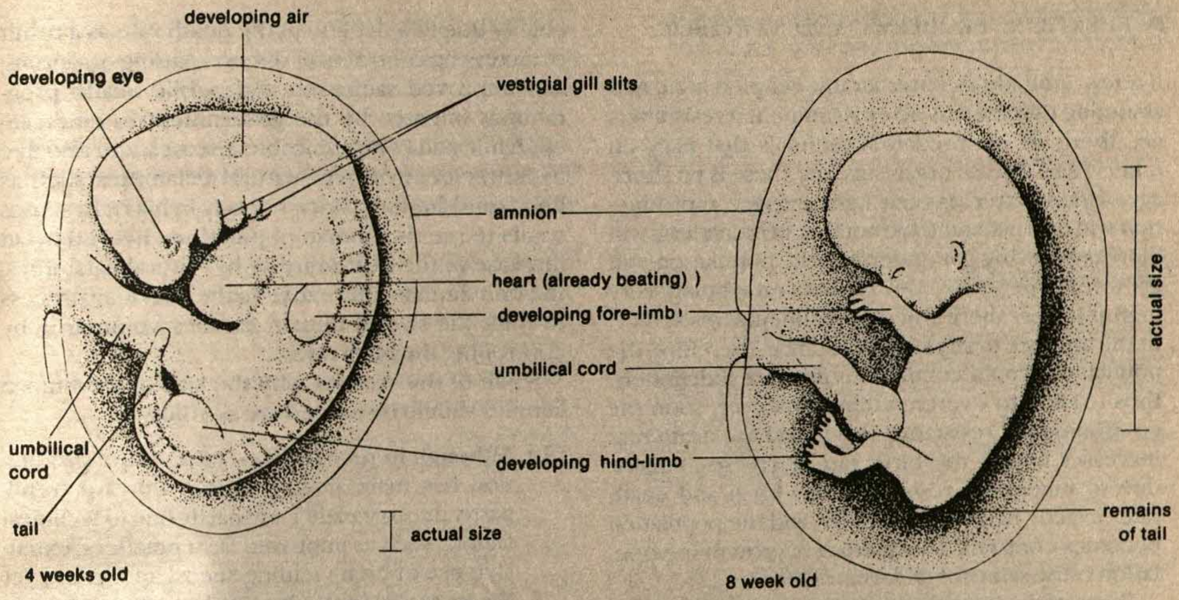
FIG. 27.6 Human foetus in uterus

At the placenta, dissolved substances from the mother's blood can diffuse into the embryonic blood, and also from the embryonic blood into the mother's blood. Dissolved oxygen, glucose, amino acids, vitamins, and some mineral salts in the mother's blood pass across from the mother's blood vessels into those of the embryo, while carbon dioxide and nitrogenous wastes from the embryo diffuse across in the opposite direction.

The **placenta** is, therefore, an organ through which an embryo

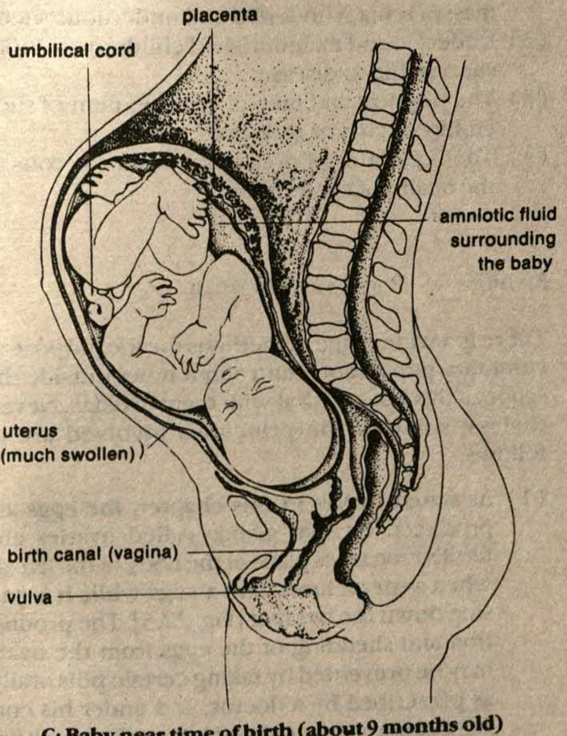
(1) receives dissolved food substances from the mother's blood;
(2) receives oxygen from the mother's blood;
(3) gets rid of its carbon dioxide and nitrogenous waste, which are ultimately thrown out of the mother's excretory organs; and
(4) serves as an important but temporary endocrine gland.

In human beings, the embryo (called the **foetus**) develops for nine months inside the mother's uterus [Fig. 27.7]. This period is known as the **gestation period**. At the end of this period, the foetus is ready to be born. During birth, the involuntary muscles of the uterus wall begin to contract rhythmically in order to force the foetus out of the uterus into the outside world. This process is also aided by the contractions of the wall of the abdomen. The umbilical



A: Embryo about 4 weeks old (5 mm long);

B: Embryo about 8 weeks old (30 mm long);



C: Baby near time of birth (about 9 months old)

FIG. 27.7 Three stages in the development of embryo

cord is cut immediately after birth by the doctor and the remains wither and fall away, leaving a scar or pit called the **navel**, in the middle of the abdomen or belly. Soon after birth the newly born baby takes its first breath, accompanied by crying.

TWINS

Sometimes a fertilised egg divides into two parts and each part develops separately into a normal embryo. Such parts, known as **twins**, are **identical** and are of the same sex. However, if two eggs are released from the ovary and fertilised simultaneously, twins with **different** sexes may result. Such twins are **fraternal** (not identical).

POPULATION: PROBLEMS AND CONTROL

If a few individuals enter an unoccupied area, and assuming that there is no environmental resistance, i.e., there are no predators (animals that prey on others) and disease organisms, and there is no shortage of food, water, oxygen, light or space, reproduction will take place and the number of individuals will increase. Having got underway, the population will grow exponentially, the growth rate being very high as long as there is no environmental resistance. In the absence of any such resistance, therefore, the population would continue to increase indefinitely, thus leading to overcrowding. However, soon the environmental resistance sets in and the death rate increases and/or the birth rate decreases. Finally, due to increasing resistance, the birth and death rates exactly balance each other, and the population becomes constant. This pattern of growth in population is the same for all forms of life.

From time immemorial, man has always been engaged in the process of altering his environment and fighting against environmental resistance. In recent times, with modern and improved techniques of agriculture, improved sanitation and public health, and increasing control over disease organisms, there has been a remarkable decrease in the death rate and a consequent population explosion. Based on United Nations data, the world human population increased by less than 1500 million during the century from 1850 to 1950; by about 400 million from 1950–60; and further by about 652 million during the decade 1960–69. Assuming that the 1960—69 growth rate is maintained, the population may well rise from 3552 million in 1969 to 20,000 million in 2045 and to 40,000 million in 2080. If the growth rate continues in this manner it is estimated that, in the year 2500, there would be just standing room only for man on this planet!

In India, the census held in 1901 estimated the population as 238 million. It grew to 361 million in 1951 (51.5 per cent increase in 50 years) and further from 361 million in 1951 to 684 million in 1981 (89.4 per cent increase in only 30 years). With the present rate of growth, the population in India will be 1000 million by the year 2000, which will be very close to the total world population as it was in 1850.

The explosive growth of human population, especially in developing countries, is one of the most pressing problems and is the root cause of most of our economic and social problems. As stated earlier, the recent increase in human population is chiefly due to a decline in the death rate as a result of increasing control over disease-causing organisms, and improved sanitation and public health programmes initiated by the government to eradicate epidemic and communicable diseases, and also due to better control over natural calamities such as floods and famines. Since nobody in his right senses wants to see the human population checked by an increase in the death rate or by natural calamities, the only human alternative is the social awareness to limit the size of human families voluntarily by controlling the birth rate.

Some of the reasons why the size of the human families should be limited are as follows:

(1) Although in recent times agricultural production has maintained a steady upward trend, partly due to weather and partly due to technical factors, such as improved farm practices, extensive use of high-yielding seeds, and so on, yet the increase is not substantial and proportionate to the increase in population. Consequently, the masses remain underfed and undernourished.

(2) Underfed and malnourished children are more susceptible to disease.

(3) The physical and mental development of such children remains retarded.

(4) The high rates of pregnancy are dangerous to the health of the mother.

METHODS OF POPULATION CONTROL

There is a wide range of methods for the purpose of voluntary population control but it lies outside the scope of this book to deal with them in detail. Nevertheless, some of the principles involved are as follows:

(1) As stated earlier in this chapter, the eggs are produced by two glands called ovaries and fertilisation takes place in the body of the female when a sperm fuses with an egg while it is passing down the oviduct [Fig. 27.5]. The production and shedding of the eggs from the ovary may be prevented by taking certain pills orally, as prescribed by a doctor, and under his constant supervision. Although the pills have been in use for a number of years, the specialists continue to have serious reservations about their long-term effects.

(2) The movement of the eggs along the oviduct may be prevented by tying off the oviduct or the release of the sperms may be prevented by

tying off the sperm duct. These methods require minor surgery. By another surgical process, the oviduct and the sperm duct can be opened, as and when desired.

(3) The sperms and eggs may be prevented from fusion by the use of physical barriers called rubber contraceptives or by chemicals which inactivate or kill the sperms.

(4) As stated earlier in this chapter, the fertilised egg travels down the oviduct and after about a week it becomes fixed to the uterus by sinking into its wall. The fertilised egg may be prevented from fixing itself to the uterus by the insertion of devices called **intrauterine devices** into the uterus. One such device is the **copper T**, which should be inserted by a doctor only.

(5) After the fertilised egg gets fixed to the uterus and starts developing, it may be removed by a specialist doctor. This is called **medical termination of pregnancy**. Since this is a very drastic method, which is also a very unpleasant experience for the mother, it is neither desirable nor practicable as a regular method of control.

EXERCISES

1. Name the main reproductive organs in the human male and female and state the function of each organ.
2. What is puberty and when does it normally occur in human beings? Name some secondary sexual characteristics which appear at puberty in (a) the male and (b) the female.
3. What is fertilisation? How and where does it take place?
4. Where does the embryo grow? How does it obtain the food and oxygen required for survival and how are its waste products excreted?
5. What do you understand by the term 'gestation period'? How long is this period in human beings?
6. List the problems associated with population explosion in India.
7. Why is it necessary to have planned families?
8. Are the methods for voluntary population control, in general, popular in India? Discuss with reasons.

Part 6: Health

CHAPTER 28

Disease and Hygiene

The word 'disease' signifies a departure from a normal state of health. A person may be regarded as suffering from disease if and when his or her body does not function normally. Disease includes a very wide variety of conditions and disorders of the body, both major and minor. 'Disease' encompasses everything from a simple headache or mild fever to fatal injuries or wounds or fatal disorders such as cancer.

Ever since man came into being, he has been a victim of a large number of diseases. Primitive man regarded disease as the result of an evil influence exercised by a god or some supernatural power. He believed that gods and supernatural powers punished and tortured him for his misdeeds by causing painful illnesses in him. It was also a common belief (which still persists in some parts of the world) that 'devils' and 'evil spirits' enter the body to make a person ill. Later, breathing foul air, particularly the air of swamps, was held to be responsible for fever. Such irrational beliefs and ideas dominated for hundreds of years. But during the last two to three hundred years, men of science have begun to understand the true nature of diseases. One of the greatest scientific achievements in the history of mankind was the demonstration by Pasteur, Koch, and others, in the nineteenth century, that germs or microbes cause disease. Microbes are very small organisms which are not normally visible to the naked eye and can be seen only with the help of a microscope.

In addition to microbes, there are various other factors which cause disease: for instance, larger organisms such as worms; lack of certain important food substances such as vitamins and mineral salts; and functional disturbances in organs such as the heart, kidney, liver and pancreas, are also known to result in diseases.

DISEASES CAUSED BY ORGANISMS

Disease can be caused by various types of microbes or microorganisms as well as by some larger animals such as hookworms, pinworms, threadworms, and tapeworms.

Microbes are too small to be seen without a microscope and are therefore called microorganisms. Some of the microbes associated with disease are as follows.

BACTERIA

Bacteria are very small organisms, but they are larger than viruses, and can be seen with an optical (light) microscope. Unlike viruses, they can grow and reproduce even when they are not inside a living cell. Bacteria are found everywhere: in air, water, soil, in and on decaying organic matter and even in and on living organisms. They are one-celled organisms and vary in size from 0.5 to 5.0 microns in width and from 2.0 to 10.0 microns in length (1 micron = 1/1000 mm).

Bacteria were earlier classified by biologists as plants, mainly because they have cell walls. Now most biologists group them as **prokaryotic** organisms, i.e., organisms which do not have a nuclear membrane. (Others which do have such a membrane are called **eukaryotic** organisms.) Their cell wall consists of fats and proteins, but no cellulose. The nuclear material is not enclosed in a nuclear membrane. Cytoplasm contains granules of reserve food such as glycogen and lipids. It also contains ribosomes, but no mitochondria, Golgi bodies, endoplasmic reticulum or large vacuoles [see Fig. 28.1].

Types of bacteria: According to their shapes, bacteria can be classified as follows [Fig. 28.2]:

(a) Cocci (singular : coccus) or spherical bacteria, which are found singly or in groups;
(b) Bacilli (singular : bacillus) or rod-shaped;
(c) Spirilla (singular : spirillum) or spiral-shaped; and
(d) Vibrios (singular : vibrio) or comma-shaped.

Bacteria are generally thought to be dangerous and responsible for causing diseases. However, some bacteria are extremely useful to mankind, as discussed earlier in Chapter 9, while others called **pathogenic** bacteria cause diseases such as cholera, plague, leprosy, tetanus, diphtheria, typhoid, bacillary dysentery, tuberculosis, pneumonia, boils, septic conditions of wounds, and so on. The harmful effects of pathogenic bacteria are chiefly due to poisonous toxins that they secrete.

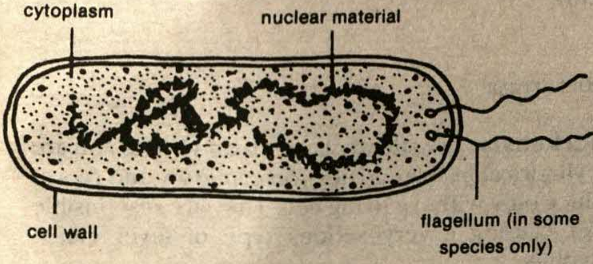


Fig. 28.1 A typical bacterial cell

Bacterial control: Some of the methods which help us in fighting against pathogenic bacteria are as follows:

Sterilisation: Sterilisation is the procedure of removing all the bacteria from an object by killing them through either heat (steam under pressure, in an autoclave) or chemicals (such as penicillin, streptomycin, sulpha drugs, alcohol, carbolic acid, phenyl, and so on). Surgeons ensure that all their surgical instruments, dressings, and clothes are sterilised before going into the operation theatre. This ensures that bacteria do not reach the patient and infect his body during an operation.

Exposure to sunlight: Household articles such as clothes, mats, bedding, and rugs should be exposed to sunlight, as often as possible.

Filtration: Bacteria can be removed from water meant for human consumption or from other liquids by filtration through porcelain filters.

(Other methods for preventing bacteria from spoiling our foodstuff have already been discussed earlier in Chapter 9.)

VIRUSES

Viruses are the simplest organisms which exhibit the fundamental properties of life. In fact, they are

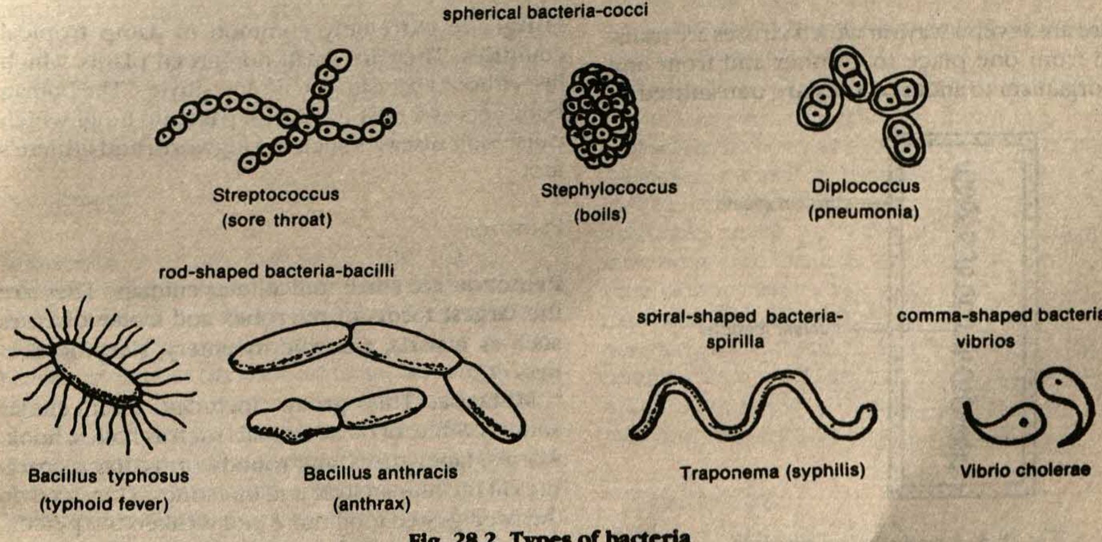


Fig. 28.2 Types of bacteria

the smallest particles of living matter and can grow, assimilate food substances, reproduce, pass on their characteristics to their offspring, and mutate. However, they show no signs of life unless they are inside the living cell of a host. Because of this peculiar characteristic, their nature still remains debatable. The question whether they are chemical and inanimate or biological and animate entities still remains unsolved. Because they show characteristics of life inside the living cell of a host, the biologists call them microorganisms.

Viruses are so small that they can pass through a filter whose pores are small enough to retain bacteria. They cannot be seen with an optical (light) microscope. A more powerful device called electron microscope is needed to observe them. They vary in size from 15 to 450 millimicrons (1 millimicron = 1/1,000,000 mm).

The virus has a protein sheath or an outer layer which surrounds a core consisting of nuclear material, which is ribose nucleic acid (RNA) in plant viruses and deoxyribose nucleic acid (DNA) in animal viruses. Although viruses have no means of locomotion, they can reproduce and have characteristics which are transmitted from one generation to the next with the help of their nuclear material. Their shapes are variable, but generally they are either rod-shaped or spherical. They are sensitive to acids, alkalies, and alcohol [Figs. 28.3 and 28.4].

Once inside the living cell of a host, viruses interfere with the normal metabolism of the host cell and subsequently destroy it. The host cell virtually becomes enslaved by the master (virus). They can reproduce very rapidly but only within a living host cell.

There are several ways in which viruses are transmitted from one place to another and from one living organism to another. They are transmitted by (1) physical contact, (2) through air, water and soil, (3) by pollen grains, (4) by seeds, (5) by fungi, (6) by worms, (7) by insects, etc.

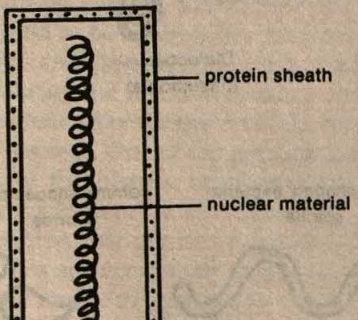


Fig. 28.3 A typical viral particle

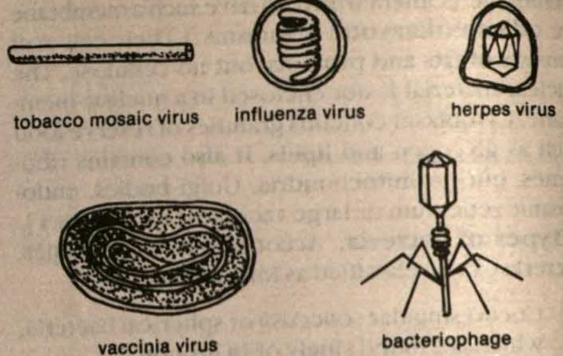


Fig. 28.4. Types of viruses

Common viral diseases of the animals are smallpox, chickenpox, cowpox, influenza, herpes, mumps, yellow fever, poliomyelitis, measles, and rabies. In plants they cause diseases such as leaf mosaic and leaf curl.

RICKETTSIAE

Rickettsiae are slightly larger than viruses and are cylindrical in shape. They too can grow and reproduce only within a living cell. They are responsible for causing a very serious type of fever called typhus.

FUNGI

Fungi are extremely common in damp tropical countries. They are small non-green plants which live either as parasites or as saprophytes. The human body acts as a host to several parasitic fungi which cause skin diseases such as ringworm and athlete's foot.

PROTOZOA

Protozoa are small, unicellular animals. They are the largest forms of microbes and cause diseases such as malaria, amoebic dysentery, sleeping sickness etc.

Metazoa: This group includes multicellular animals. Some of these animals such as flukes, hookworms, tapeworms, and roundworms, live as parasites in the human liver and intestines. They feed on the predigested food there and weaken the person, causing anaemia and a constant feeling of hunger.

CHAPTER 29

Some Common Diseases: Their Causes, Spread, and Prevention

COMMON COLD

Common cold is not caused by cold conditions as is often falsely believed, but by infection with a **virus**. After infection the virus multiplies in the mucous membrane lining the nose and throat and leads to the first symptoms of common cold, i.e., a dry and irritating feeling in the nose and throat. Colds are spread by droplet infection through coughing, sneezing, loud talking, etc. The spread of infection can be prevented by the same methods as for other air-borne diseases, and also by avoiding dust, exposure to cold, and rapid changes of body temperature. Colds weaken the patient's resistance to infection by other more dangerous disease organisms. Therefore, a cold must **never** be neglected.

INFLUENZA

Influenza is a very infectious viral disease that spreads very quickly from the sick to the healthy by droplet infection through coughing, sneezing, loud talking, etc. The symptoms of the disease include headache, pain in the back and legs, shivering, high temperature, and a general feeling of weakness. To reduce the chances of infection, healthy people should avoid overcrowding and lack of ventilation. The sick persons should be isolated and the general methods of prevention of the spread of infection for air-borne diseases should be followed.

PNEUMONIA

Pneumonia indicates the infection and inflammation of the lungs caused by air-borne bacteria. The disease spreads by droplet infection. Persons suffering from a neglected cold or influenza, which lower the body resistance, generally develop pneumonia quickly. The early symptoms of pneumonia are very similar to those of colds and influenza but the fever rises to a very high degree. There are shooting pains in the chest, sides, or shoulders and these become worse along with the effort to breathe deeply. The cough is very painful and the sputum may be slightly coloured with blood.

There is no specific method of procuring immunity against this disease. However, it is very important that all infections of the nose, throat, and respiratory organs be promptly and properly attended to by a doctor, and diseases, such as cold and influenza, must never be neglected, since these infections may often be followed by pneumonia as they reduce the resistance of the body. Fatigue, exposure to cold, and rapid changes in body temperature, poor nutrition and anything else that reduces body resistance should be avoided. Spread of infection is prevented by observing the general rules for preventing air-borne diseases.

TUBERCULOSIS

Tuberculosis, commonly known as TB, is a very serious infectious disease caused by the **bacteria** *Mycobacterium tuberculosis*. The bacteria may attack bones, joints, kidneys, adrenal glands, etc., but in 90 per cent of the cases, the affected organs are the lungs. It is well known that 'tuberculosis comes from tuberculosis'. This disease spreads by contact with the infected persons and through the bacteria they throw out while coughing, sneezing, spitting, talking, etc. It is an example of a typical air-borne disease spreading by droplet infection. The bacteria causing TB are present almost everywhere, but everyone who picks up the bacteria does not necessarily contract TB. Only those persons, who are victims of poor nutrition, overwork, insufficient rest, and living in overcrowded, poorly ventilated, and unsanitary conditions are most susceptible to the disease. The disease may take a long time to develop after the first infection but this depends on a number of factors such as the age of the person, his health and general living conditions.

The most common form of TB, the lung TB, begins with tiredness (which is not relieved by rest), unexplained loss of weight and appetite, persistent cough and afternoon fever, followed later by spitting of blood-coloured sputum. These are some of the danger signals and need prompt medical attention. This disease can be effectively treated by modern drugs such as Streptomycin, Isoniazid (INH) and para-amino salicylic acid (PAS). Also, complete rest, especially in the early stages, is essential. Vaccination against TB with BCG vaccine is effective in building up an immunity against the disease.

DIPHTHERIA

Diphtheria is an acute infectious disease caused by specific **bacteria**. It is commonest in young children up to the age of five years and is very dangerous to them. It is spread by droplet infection of the healthy by the sick while coughing and sneezing. Children may also become infected by drinking from an infected cup or sucking an infected object. The symptoms of the disease include high fever and sore throat with patches of grayish membrane on the tonsils and in the throat. If it is not treated in time the membrane can choke the patient to death.

The disease can be prevented by acquiring active immunity through inoculation which provides a lasting immunity. All infections of the throat must be medically checked up. Healthy persons must not be allowed to come in contact with the patients.

CHOLERA

Cholera is a highly infectious intestinal disease caused by the **bacteria** *Vibrio cholerae*. The bacteria are water-borne. A patient suffering from cholera passes bacteria in his stools (and also during vomiting) and from there these find their way through seepage in the ground, into streams, wells, and rivers. They also enter articles of food through houseflies. When the contaminated water and food are taken in by healthy persons, the disease spreads quickly. The disease begins with acute diarrhoea (loose motions) and vomiting accompanied by abdominal pains. The stools appear like rice water. Owing to the frequency of loose motions and the large quantity of water passed, the patient rapidly becomes dehydrated, and his body and limbs shrink, until he looks like a skeleton. The death rate is very high and over 50 per cent of those who fall victim to this disease die unless medical treatment is provided very quickly.

Cholera can be prevented by the injection of **cholera vaccine** which gives an artificially acquired immunity. For the general prevention of the disease, foods exposed to flies must never be consumed, and water suspected of pollution should be boiled and chlorinated before drinking. The sick must be isolated and the hands should be thoroughly cleaned after coming in contact with the patient. In fact, cholera can be completely prevented by proper sanitation. The waste products of the patients must be properly disposed off.

TYPHOID

Specific **bacteria**, namely, the **typhoid bacillus** (*Salmonella typhi*) are the cause of typhoid. The bacteria are present in the faeces and urine (and sometimes in the saliva and perspiration) of a patient. The disease spreads mainly by consuming contaminated food, ice, water, milk, and also by direct contact with the sick. Houseflies act as carriers of the bacteria from the infected wastes to the human food. Typhoid is a serious illness characterised by high fever, acute headache, and rose-red blotches on the skin. The disease can be effectively cured by antibiotics such as Chloramphenicol.

Protection against typhoid is provided by **anti-typhoid inoculation** which should be taken every year. The most important factor in preventing typhoid fever is, however, proper sanitation, clean personal habits, avoiding foods and drinks exposed to houseflies, and proper disposal of the patient's wastes so that the typhoid bacteria cannot get into foods or beverages.

TABLE 29.1 : SOME INFECTIOUS DISEASES

TYPES	MAIN SYMPTOMS	CAUSATIVE AGENT	USUAL AGE OF ATTACK	INCUBATION PERIOD	MEANS OF SPREAD	PREVENTION
1. Common cold	Fever, headache, running nose. More prevalent in cold weather	Virus	All ages	2 days	Air	Avoid crowded places. Cover nose and mouth when coughing and sneezing.
2. Influenza	Headache, fever, fatigue, drowsiness, general ache all over the body. Sometimes dry cough and painful eyes. Running nose is less common.	Virus	All ages	1–4 days	Air	Avoid crowds, changes in temperature, and fatigue. Cover nose and mouth when coughing and sneezing because secretions from nose and throat are infected.
3. Pneumonia	Acute infection of lungs, high fever, shaking chills, pain in chest, painful cough, rust-coloured sputum.	Bacteria	All ages, but dangerous to very young and old	—	Air	Avoid fatigue, changes in temperature and poor nutrition. Prompt treatment of less serious respiratory infections like common cold and influenza.
4. Tuberculosis	Persistent cough, afternoon fever, fatigue, loss of weight and appetite, spitting out of blood or blood-coloured sputum.	Bacteria	All ages	—	Air	BCG vaccination. Avoid overcrowded, polluted and dusty living conditions and environment. Avoid poor nutrition.
5. Diphtheria	Highly infectious. High fever, sore throat, patches of grayish membrane in the throat and on the tonsils.	Bacteria	All ages, but commonest in and dangerous to children up to the age of 5 years.	2–10 days	Air	Vaccination. Avoid contact with infected persons and materials. All throat infections must be medically attended to.
6. Cholera	Acute diarrhoea, vomiting, abdominal pains, unconsciousness.	Bacteria	All ages	1–3 days	Water, food, contamination by houseflies.	Vaccination. Control of houseflies Proper sanitation. Avoid exposed food and drinks.
7. Typhoid	High fever, acute headache, rose-red blotches on the skin, diarrhoea or constipation.	Bacteria	All ages	7–21 days	Water, food, contamination by houseflies.	Anti-typhoid inoculation. Control of houseflies. Avoid exposed food and drinks. Proper sanitation. Clean personal habits.

TYPES	MAIN SYMPTOMS	CAUSATIVE AGENT	USUAL AGE OF ATTACK	INCUBATION PERIOD	MEANS OF SPREAD	PREVENTION
8. Dysentery	Frequent and watery motions mixed with blood and mucus; severe abdominal pain.	Bacteria and *Entamoeba*	All ages	—	Food and water,also through houseflies.	Proper disposal of faeces. Avoid drinks and food exposed to houseflies and cockroaches.
9. Malaria	High fever, shivering, headache, extreme thirst.	Plasmodium	All ages but usually adults	8–10 days	Bite of infected female *Anopheles* mosquito.	Anti-malarial drugs. Prevention of the breeding and destruction of adult mosquitoes. Avoid mosquito bites.
10. Scabies	Irritation of skin, itching, rows of oval spots and watery blisters on skin.	Itch mite	All ages	8 days	Direct personal contact and infected clothes.	Good personal hygiene. Frequent washing and cleaning of skin.

DYSENTERY

Dysentery is a disease that affects the large intestine and is caused by either bacteria (**bacterial dysentery**) or by *Entamoeba*, a unicellular animal (**amoebic dysentery**). Motions become frequent and they are watery and mixed with blood and mucus. There is often severe pain in the abdomen. The microbes causing both types of dysentery are passed out along with the patient's faeces. From the faeces, the houseflies and cockroaches may carry the microbes to foods and drinks. Hence, the most effective way of preventing the spread of the disease is the proper disposal of faeces, and avoiding foods and drinks exposed to houseflies and cockroaches.

MALARIA

Malaria is caused by the **malarial parasite** (*Plasmodium*) which belongs to the group of unicellular animals called protozoa. The disease is characterised by shivering, high fever, and profuse sweating, often accompanied by headache and extreme thirst. The disease spreads by the bite of infected female *Anopheles* mosquito, which carries the microbes of the disease from infected persons to healthy persons. The disease can be controlled by the use of antimalaria drugs such as Quinine, Chloroquine, Mepacrine, and Peludrine.

Malaria can be prevented in two ways: **first**, antimalarial drugs can be taken at periodic intervals; and **secondly**, mosquitoes can be prevented from biting a person and passing on the disease. This method has been discussed more fully in an earlier chapter.

SCABIES

Scabies is a skin disease caused by a small animal called the **itch mite** which is about 0.3 mm in length. The female itch mite burrows under the outer skin to lay her eggs. The eggs hatch in about eight days and attack fresh areas of the skin. While moving on the skin, the mite makes tracks which can be clearly seen as fine raised lines or rows of thin, oval spots and watery blisters. The irritation and itching are very acute and one is forced to scratch oneself. The disease is spread from person to person by direct personal contact, which must be avoided as a preventive measure as also the handling of infected clothing. General personal hygiene with frequent washing and cleaning of the skin prevents attacks by these parasites.

PARASITES

Parasites are those living organisms which live temporarily or permanently in or on other living organisms. Such organisms are called **hosts**. The parasites derive benefits from the hosts and harm them in the process. In other words, the parasite gains, but the host loses. Some parasites live inside the body of the host (**endoparasites**), while others live on the surface of the host (**ectoparasites**). Some parasites live on, or just beneath, the skin. Others live in the alimentary canal, still others in tissue fluid between the cells, and some live inside the cells. Some parasites feed on the tissues and cause much harm, even death, to the host as a result of sheer damage of the cells. For example, *Plasmodium*, the malarial parasite which attacks our liver cells and red blood cells and causes malaria. Some parasites do not directly damage the cells but harm the host by liberating toxic chemicals into its bloodstream, e.g., *Trypanosoma*—a one-celled animal like *Plasmodium*—which causes sleeping sickness in man. The least harmful parasites are those that feed on the host's digested food without damaging the tissues, e.g., *Taenia solium*, which lives in the intestines. Some parasites such as the filaria worm live and reproduce in the lymphatic system and lead to enlargement of the legs, breasts, and so on. This indicates a disease called **elephantiasis**.

We shall now discuss some parasites in greater detail and the ways to control them.

Plasmodium: This is a one-cell animal, the malarial parasite, which causes malaria in man. The disease is transmitted by the female *Anopheles* mosquito.

When an infected female *Anopheles* mosquito bites a healthy man to suck his blood, thousands of parasites are injected into his blood along with the mosquito's saliva. The parasites enter the liver cells and red blood corpuscles [Fig. 29.1] where they grow and multiply asexually by fission. As their number increases, more and more liver cells and red blood corpuscles are attacked and consequently damaged. The parasites release poisonous toxins

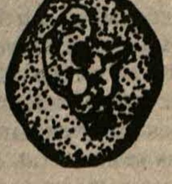


Fig. 29.1 Plasmodium inside red blood corpuscle

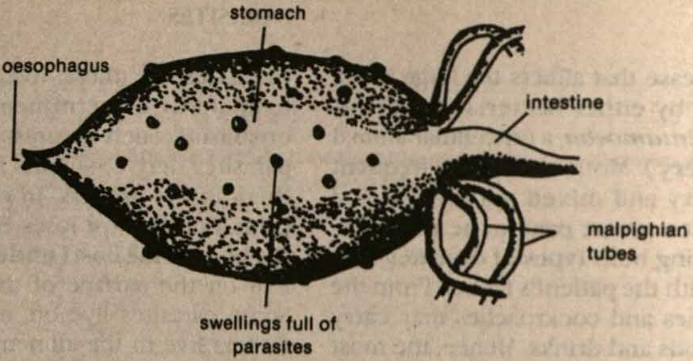


Fig. 29.2 Stomach of an infected *Anopheles* mosquito

into the bloodstream and an accumulation of these toxins causes malaria in man. When a female *Anopheles* mosquito bites such an infected man to feed on his blood, thousands of parasites are sucked up with the blood. The parasites settle in the wall of the stomach of the mosquito and reproduce there sexually. The number of parasites increases once again. When this infected mosquito bites another healthy man, it again injects thousands of parasites, along with its saliva, into his bloodstream, and the same cycle is repeated.

Thus the malarial parasite has two hosts, man and mosquito, and it spends a part of its life cycle in each. The mosquito does not suffer from malaria or any ill effects but it just serves as a means of transfer of the parasite from one human being to another and also as a means of the continuation of its race, if by chance the patient dies or the parasites get killed by protective biological activities in the patient or by the drugs which the patient takes to cure malaria.

Controls against Malarial Parasite

Since mosquitoes transfer the parasite from one human being to another, it is essential to learn how to control their activities and reduce their number as a check against the transmission of the disease. A reduction in the number of mosquitoes will have a corresponding check on malaria. Some of the more effective methods of dealing with them are as follows.

Personal protection. In areas infested with mosquitoes, we should wear clothes which leave as little of our skin exposed as possible. The exposed parts of our bodies may be treated with mosquito repellents such as mustard oil, citronella oil, and anti-mosquito creams. Doors and windows should be screened with mosquito-proof gauze and mosquito nets should be used around beds while sleeping at night.

Destruction of adult mosquitoes. This can be achieved by spraying liquid insecticides such as DDT and Flit all over the house, especially in nooks and corners. Fumigation with sulphur dioxide gas is also effective.

Destruction of larvae. This is one of the easiest methods of control. If paraffin or kerosene oil is introduced into stagnant water where larvae are present, it forms a layer on the water and suffocates both larvae and pupae by blocking their respiratory openings. Liquid insecticides are effective in a similar way. Also, fishes such as minnows, sticklebacks, and *Gambusia* feed on larvae and pupae, and may be introduced into ponds to eradicate them.

Elimination of breeding places. The very breeding of mosquitoes can be minimised by ensuring that our cities, towns, and villages are kept free of stagnant ponds, open drains, and ditches. Water should not be allowed to stand in lanes and streets, and the openings of drains should be cleaned regularly.

For the destruction of the malarial parasite in the human host, there are a number of anti-malarial drugs such as Quinine, Paludrin, Atabrin, Plasmochin, Avinacrine, Pamaquine, and Mepacrine.

Taenia solium. This is a parasite living inside the intestines of a human being. It has a creamy white ribbon or tape-like body which could extend up to 5 metres when fully mature. Because of its appearance it is also known as **tapeworm** [Fig. 29.3]. It has a small head called **scolex** [Fig. 29.4], which is attached to the wall of the intestine with the help of hooks and suckers. Behind the head is a growing

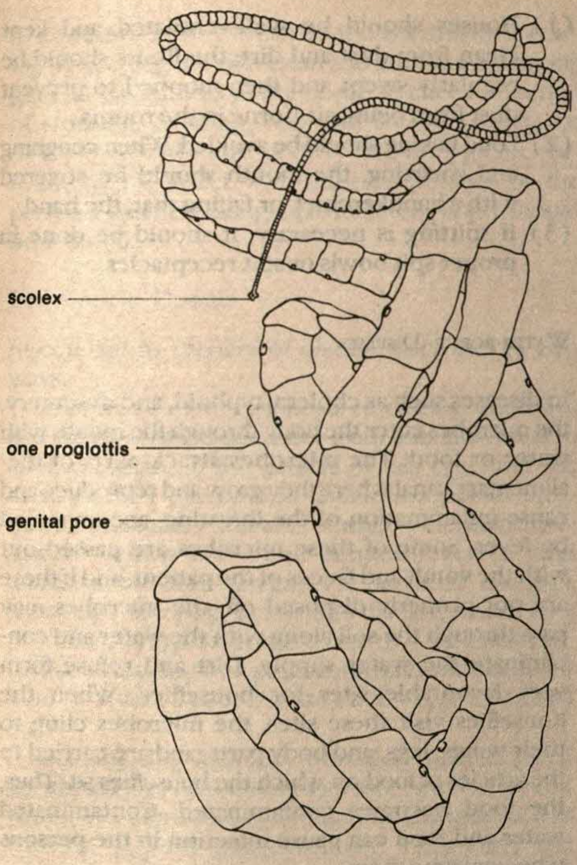


Fig. 29.3. ***Taenia solium*** **— the tapeworm**

region where numerous identical segments called **proglottis** are budded off. As the segments increase in age they are pushed further backwards by the newer ones that are formed behind the head. The oldest segments are farthest from the head. The animal has no mouth or alimentary canal but it absorbs nutrients from the partly digested food in the intestine with the help of its long body which presents a large surface area for absorption. Each segment contains a complete set of male and female reproductive organs and eventually these become a bag full of fertilised eggs enclosed in protective shells. At the hind end, the mature segments containing fertilised eggs break off from the body into the intestine. These are then passed out in the faeces. In each egg a small embryo with six hooks is produced.

The embryo remains dormant until the eggs are eaten by another host, which is generally a pig that feeds on the human faeces and other wastes. Inside

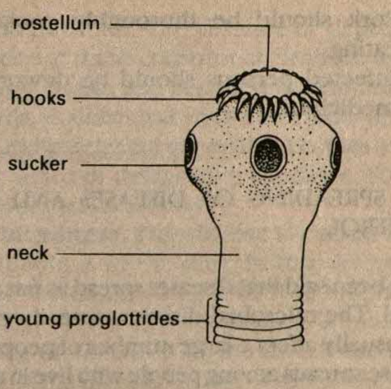


FIG. 29.4 Scolex of tapeworm

the intestine of the pig, the shell dissolves and the embryo comes out. The embryo bores its way through the walls of the intestine into the blood vessels. It is carried to the muscles by the blood stream. Here the embryo encysts and develops into a stage called **bladderworm** in about three months. The bladderworm is a small, hollow fluid-filled bladder-like structure with a scolex turned inside out internally. Nothing further happens until the bladder reaches inside the alimentary canal of man.

If undercooked meat from an infected pig is eaten by a human being, the bladderworms will be released into the intestine and develop into tapeworms. The scolex turns the right way out, loses its bladder and attaches itself to the walls of the intestine.

Controls against Tapeworm

Tapeworm infections are common in underdeveloped or developing countries, where man lives in places with unhygienic conditions and where he is in close contact with domestic animals. Some of the measures to prevent infection are as follows:

(1) Good sanitation should be provided. The untreated sewage should not be allowed to come in contact with soil.

(2) Pig farming should be done in hygienic conditions and the animals should be given clean and uncontaminated food.

(3) Pork should be thoroughly inspected before it is consumed. Measly pork—the spotted pork containing bladderworms—should not be consumed.

(4) Pork should be thoroughly cooked before eating.
(5) Infected persons should be dewormed with medicines.

THE SPREADING OF DISEASES AND THEIR CONTROL

It has been said that diseases spread as fast as man can travel. The microbial diseases spread very quickly and usually affect a large number of people. When a disease spreads among people who live in a particular locality or a confined group, it is called **endemic disease**. When a disease spreads throughout several adjacent localities, or throughout a city, or even throughout a country, it is called an **epidemic disease**. If it further spreads until it becomes world-wide, it is called a **pandemic disease**.

There are four main modes or means by which diseases pass from one individual to another: (a) air; (b) food and water; (c) skin contact; and (d) insects.

AIR-BORNE DISEASES

When a person suffering from a particular disease coughs, sneezes, breathes out deeply, or talks loudly, the microbes of the disease are blown out of his mouth with small droplets of saliva. If a healthy person is nearby, the droplets are inhaled by him and he may get infected with the same disease. Diseases which spread by means of organisms due to direct contact between individuals are called **infectious diseases**. Extremely small droplets, containing microbes, remain suspended in the air, while larger droplets settle down in the dust on the ground. Spitting also deposits the microbes in the dust. Soon the saliva and the spittle dry up; the microbes, however, remain alive but inactive in the dust. When the dust is disturbed, the microbes become **air-borne**. These are then inhaled by healthy persons who may thus be infected.

The common bacterial and viral diseases which spread in this way (air-borne) are as follows:

(1) **Bacterial diseases**. Tuberculosis, pneumonia, diphtheria, scarlet fever, and all infections of the throat.
(2) **Viral diseases**. Common cold, influenza, measles, smallpox, chickenpox, and mumps.

Prevention against air-borne diseases becomes effective only when general health rules are properly observed. Some of these are:

(1) Houses should be well-ventilated and kept clean from dust and dirt; the floors should be regularly swept and then mopped to prevent dust from being air-borne in the rooms.
(2) Loud talking should be avoided. When coughing and sneezing, the mouth should be covered with a handkerchief, or failing that, the hand.
(3) If spitting is necessary, it should be done in proper spit bowls or spit receptacles.

WATER-BORNE DISEASES

In diseases such as cholera, typhoid, and dysentery, the microbes enter the body through the mouth with water or food. The microbes attack parts of the alimentary canal where they grow and reproduce and cause inflammation of the intestine, accompanied by fever. Some of these microbes are passed out with the vomit and faeces of the patient, and if these are not properly disposed off, the microbes may pass through the soil along with the water and contaminate the water supply. Dirt and refuse form very favourable sites for houseflies. When the houseflies visit these sites, the microbes cling to their wings, legs, and body parts, and are carried to the articles of food on which the houseflies sit. Thus, the food becomes contaminated. Contaminated water and food can cause infection in the persons who consume them.

The prevention of water and food-borne diseases from spreading may be achieved by improving sanitation so that human faeces and wastes can be properly disposed off. The surroundings of the house should be kept clean. A well-ventilated, sufficiently lighted, and airy house will attract fewer flies. Civic authorities should arrange to safeguard the water supply and provide clean water. Food articles exposed to flies and made from contaminated water must not be consumed. Spoilt and decayed food must never be consumed. Food, especially meat, must be properly cooked to prevent infection caused by certain worms. Furthermore, hygienic methods of preparing, storing, and serving food are essential.

CONTACT DISEASES

Diseases spread by skin contact are called **contagious diseases.** Microbes on the skin of a patient may be transferred to a healthy person by direct contact, or by using the clothes, towel, comb, etc., belonging to the patient. Some common contagious diseases are eczema, ringworm, yaws, and leprosy.

Contagious diseases can be prevented from spreading by keeping the skin clean and also by maintaining general cleanliness of the home to check infection of clothing, bedding, rugs and so on. Contagious diseases spread more in dirty and unhygienic surroundings. Contact with infected persons or the personal objects belonging to infected people should be avoided.

INSECT-BORNE DISEASES

Insects act as carriers of disease microbes in two ways:

First, insects serve as hosts to disease microbes and transmit these microbes from one individual to another. Some of the insects of this type and the diseases they spread are: female *Anopheles* mosquito—malaria; female *Culex*—elephantiasis; *Aedes*—yellow fever and dengue fever (a viral disease); rat flea—plague (a bacterial disease); tsetse fly—sleeping sickness (a disease caused by a protozoon, *Trypanosoma*); sand fly—Oriental sore (a disease caused by a protozoon, *Leishmania*) and sand fly fever (a viral disease); lice—typhus, and so on.

Secondly, they feed in or around dirty places (such as rubbish and refuse heaps) wastes such as faeces, vomit, etc. of persons suffering from diseases such as cholera, typhoid, and dysentery. They carry the microbes of these diseases to articles of food. When the contaminated food is consumed by healthy individuals, infection becomes inevitable. Some of the insects of this type are houseflies and cockroaches. Houseflies also spread diarrhoea, leprosy, tuberculosis, trachoma, etc. Cockroaches do not feed on wastes such as faeces or vomits. They just frequent dirty places and carry microbes on their body which contaminate the food meant for human consumption.

Since rats act as hosts of rat fleas, which spread plague, they invariably constitute a danger to human beings. Some other diseases spread by rats are leptospirosis, typhus, and relapsing fever.

The prevention of insect-borne diseases such as malaria, typhoid, and cholera depends on our control over such insects as houseflies and mosquitoes. We have already discussed the measures which need to be taken against these insects.

DISEASES NOT CAUSED BY ORGANISMS

The constituents and also the importance of a balanced diet have already been discussed in the chapter on nutrition. The absence or depletion of one or more of these constituents leads to a condition of poor health and retarded development. In other words, an individual whose diet is not properly balanced and is deficient generally becomes a victim of one or more of **deficiency diseases**. Some of these diseases are as follows:

Night blindness. This disease is caused by the lack of vitamin A in the diet. In this disease the affected person can see clearly **only** in bright light.

Beri-beri. This deficiency disease is caused by the absence of vitamin B in the diet. Some of the symptoms of the disease are loss of sensation, weakness of the limbs, pain in the muscles, and swelling of the legs.

Pellagra. If a person develops rashes and sores on the skin, sore joints and muscles, loss of appetite, diarrhoea, general weakness, and so on, it may be due to pellagra, a deficiency disease caused by lack of **nicotinic acid**, a B-complex vitamin.

Scurvy. Deficiency of vitamin C leads to scurvy, which is characterised by swollen and bleeding gums, weakening of the walls of the blood capillaries, anaemia, and painful swellings round the joints and in the limbs.

Rickets. A deficiency of vitamin D causes this disease, especially in children. The bones remain soft and weak, and the teeth start decaying.

Goitre. In this disease, caused by the lack of iodine in the diet, the thyroid gland becomes enlarged.

Kwashiorkor. This disease affects children whose diet is persistently lacking in essential proteins. This disease is characterised by anaemia, wasting, dependent oedema, and a fatty liver.

Anaemia. Anaemia is caused due to lack of iron in the diet. The symptoms of the disease are a pale yellow skin colour, loss of appetite, tiredness, shortness of breath, palpitation of the heart, and general weakness.

HYGIENE

There are thousands of different types of microbes in our environment and many of these are always ready to 'invade' the human body. Unless we maintain proper cleanliness and a hygienic condition of the body, these will attack us and cause diseases.

The following main points with respect to personal cleanliness must be carefully followed to ward off the microbes.

The hands. The spores of microbes are very plentiful in dust and dirt and on most objects which we handle every day. The sweat on the hands and the oily secretions from the skin provide excellent conditions for the microbes to thrive on. Finger nails can also harbour microbes unless these are properly cleaned. Scratching an infected part of the skin will remove microbes and transfer them to an uninfected portion of the skin. Similarly, when young intestinal worms collect in the skin folds around the anus and cause irritation, one is tempted to scratch. The worms are removed beneath the finger nails and subsequently they find their way to the mouth while eating and so cause reinfection.

Hands and finger nails must always be kept clean. Besides, the finger nails must be kept short. The hands must be washed thoroughly before meals are taken or prepared and also after going to the toilet.

The feet. Sweating of the skin, specially between the toes, makes a good breeding place for the spores of microbes, especially those causing a fungal skin infection called **athlete's foot.** Washing the feet frequently is quite helpful in removing these microbes.

When walking bare feet, one is likely to get hookworm infection through cuts in the skin. Shoes are necessary to avoid infection.

Toe nails should be kept well trimmed and clean.

When buying shoes, it is always necessary to ensure that they fit well and do not cramp the feet.

The skin. Sweat and oily secretions from the skin cause dust to stick to it easily. Such skin provides a good place for the spores of microbes to breed. Besides, it results in blocking of the sweat pores on the skin and weakens the ability of the skin to carry out its natural functions.

Washing the skin with soap and water cleans it. Taking one thorough bath every day is very useful for maintaining healthy skin. The bath should not be taken either after exercise when the body is hot with sweat or after a heavy meal.

Although fresh air and sunlight are beneficial to the skin, overexposure to strong sunlight may lead to sunburn.

Mouth and teeth. If mouth and teeth are not kept clean, food particles get caught in between the teeth and start decaying. This will not only cause foul smell to emanate from the mouth, but will also damage the teeth. The mouth must be rinsed with clean water immediately after a meal.

Very hot and cold foods must be avoided to prevent chipping of teeth enamel.

If there are cavities in the teeth, they must be filled early.

Tartar deposits, if any, must be removed otherwise these will make the gums recede and expose the teeth root, thus weakening the teeth.

Brushing the teeth in a proper way keeps them in a good condition.

Gums must be exercised by including hard fibrous food in the diet.

Since bad teeth and inflamed gums can lead to certain diseases, it is necessary to consult a dentist regularly.

Head, nose, ears, and eyes. The scalp and the hair should be kept thoroughly clean by washing with warm water and some good soap or shampoo at least once weekly. Too frequent washing is undesirable since it removes natural oil present in the hair. Suitable head gear is always advisable when long exposure to the tropical sun becomes necessary.

Breathing should be done through the nose and not through the mouth, since the hair in the nostrils filters dust and microbes from the air. The nose should be blown at regular intervals to remove the accumulated dust and microbes.

The eyes should be washed regularly. Eye strain should be avoided by using proper light. Glasses should be worn only if needed. Eyes must be protected against strong sunlight.

Loud noises and blows on the ears should be avoided as these may damage the eardrum and allow infection to develop in the ear, besides affecting hearing.

Ear wax protects the ear canal from infection and injury; and it is always wise to leave it alone. However, if the ear needs cleaning, it should be done by a doctor. Sharp pointed instruments should not be used to remove wax from the ear.

Clothing. In tropical climates, fewer clothes are always more comfortable. Light coloured or white clothes should be worn in the tropics, which provide protection against the burning rays of the sun.

The clothes should be loose fitting to allow proper circulation of air. They should be changed frequently and washed thoroughly with soap or detergent and clean water to prevent the growth of moulds, which may cause skin irritation.

AIDS TO HEALTH

Microbes enter the body mainly through wounds and cuts and also through the mouth, and the nose. Whichever way they enter, they eventually reach the blood stream. A large concentration of microbes in the blood stream leads to diseases, each disease being caused by a different kind of microbe. The human body is equipped with many natural and effective barriers which do not permit the microbes to enter the body. The layer of dead cells on the skin provides a mechanical barrier, while mucus and secretion of digestive glands offer a chemical barrier for keeping the body free of microbes. Tears also provide a form of chemical defence. If, however, the microbes are able to cross these barriers, then a further line of body defence, namely, the **antibody-producing system**, comes into action. The white blood corpuscles in the blood begin to play an important role in destroying these microbes. The white blood corpuscles attack, engulf, and digest microbes. They are known as **phagocytes**. The microbes, being parasites, obtain their food from the human body, either from dissolved food substances in the blood or from the body cells. As a result of the activities of the microbes in the body, they produce waste products called **toxins.** These toxins are poisonous and give rise to the symptoms of the actual disease. However, some powerful types of microbes cannot be destroyed by white blood corpuscles until they have been acted upon by chemicals called **antibodies** which are made by the white blood corpuscles. The antibodies are proteins and they affect the microbes or their waste products in a number of ways which are listed as follows:

(1) Antibodies called **opsonins** stick to the outer surface of the microbes and thus make it easier for the white blood corpuscles to digest them.
(2) Antibodies called **agglutinins** make the microbes stick together in clumps, thus preventing their spread and reproduction.
(3) Antibodies called **lysins** destroy microbes by dissolving their outer coats.
(4) Antibodies called **antitoxins** combine with and thus neutralise the poisonous toxins produced by the microbes.

Antibodies are produced by white blood cells in response to the stimulus of microbes present in the blood. The substances that stimulate the white blood cells to produce the antibodies are called **antigens**. Antibodies may already be present in the blood at the time of infection or they may be produced very rapidly by the white blood cells as soon as the microbes (which act as antigens at that time) attack the body. If the antibodies are not already there in the blood or are not produced quickly enough, the microbes or their toxins will give rise to the symptoms of the disease. When a person recovers from a disease, the antibodies may remain in the blood for a long or short period, but the ability of the white blood corpuscles to produce them is greatly increased so that a future attack by microbes is likely to be stopped at once and the person is said to be **immune** to the disease.

Immunity is the ability of the body to resist or tolerate the dangers from microbes. It is the inability of the body to be infected with a particular disease. If several persons are exposed to a given infection, only those who do not possess immunity to that particular infection will suffer from the disease. Immunity is due to the presence of antibodies in the blood to deal with microbes quickly and effectively, or it is due to the ability of the white blood corpuscles to produce the particular antibodies instantaneously at the time of the entry of microbes. People may possess this immunity from birth or they may get it after recovering from the attack of a disease, or it may be induced in them by vaccination or inoculation. We have two types of immunity, which are now discussed.

NATURAL IMMUNITY

Natural immunity simply means that some living beings cannot ever be affected by certain types of infection; the microbes causing these diseases cannot or will not live in those living beings. This is the immunity which people have from birth. They inherit this immunity from their parents and ancestors. Such an immunity to a particular disease enables the individual to tolerate the microbes of that disease throughout his life. All human beings have a natural immunity that protects them against infection by many kinds of microbes that produce disease in other animals and plants. For example, young dogs often die from a disease called **distemper**, but their human owners never catch this disease, i.e.. man has a natural immunity to dog distemper.

ACQUIRED IMMUNITY

When a person falls ill due to a disease, his blood produces antibodies to combat the infection. If he makes a natural recovery from that disease, he becomes immune to that disease, sometimes for his lifetime. After a single attack, his body acquires an experience that enables him to fight off any later attacks by the same microbes. His body becomes alert and responds favourably even to the slightest infection due to these microbes. Such a person is said to have **acquired immunity** against that disease. A person with acquired immunity possesses antibodies which protect him against the microbes that attack him, and hence he does not develop the disease. Smallpox is such a disease. However, immunity cannot be acquired for every disease.

An acquired immunity is either **natural** or **artificial**. The acquired immunity discussed above is naturally acquired immunity, i.e., when the body becomes resistant to a second attack of the same disease as a result of natural recovery from the previous attack. Artificially acquired immunity is produced by injecting either mild or weakened disease mircobes or killed disease microbes (active immunity), or ready-made antitoxins and antibodies (passive immunity) for a particular disease. In all these cases, live or dead microbes, or the antitoxins of antibodies act as antigens and stimulate the formation of antibodies in the blood.

Vaccination is done to produce artificially acquired immunity against infectious diseases. The biological preparations used for vaccination are called **vaccines**. A vaccine contains either (a) killed microbes or (b) mild and weakened microbes of the disease. The persons who are vaccinated do not get the disease, but the contents of the vaccine act as antigens and the blood is then able to produce the antibodies. The person who is vaccinated is able to fight the infection later on. Vaccination is done for diseases such as smallpox, tuberculosis, whooping cough, and poliomyletis. Cowpox or vaccinia virus is used as the vaccine for smallpox.

Serum is the clear, watery and yellowish part of the blood that remains when the red and white blood corpuscles, blood platelets and the blood protein called fibrinogen have been removed from it by clotting. It should be noted that serum is not the same as plasma. The breakdown is as follows:

Plasma = blood minus blood corpuscles and blood platelets.
Serum = blood minus blood corpuscles, blood platelets and fibrinogen.
= plasma minus fibrinogen.

Serum contain **antitoxins** which fight against the microbes. Antitoxins are a particular type of antibody which are produced in the body in response to the presence of an antigen or a toxin, and they combine with and thus neutralise the toxins produced by the microbes.

Serum for inoculation against particular microbes is obtained by injecting the vaccine into another animal, usually a horse. The vaccine acts as an antigen in response to which antibodies called antitoxins are produced in the blood of the horse. Gradually the horse builds up its own active immunity against the disease. A small quantity of the horse's blood is then taken; this blood contains the antitoxins. This blood is then clotted and the serum is separated. When this serum is injected into a patient's body, it will not only cure him of the disease but also give him protection against future attacks by those microbes. The immunity thus acquired is a passive one because the patient's blood is not really called upon to do anything. Further, such immunity lasts only for a few months and in order to make the immunity last longer, it is necessary to repeat the inoculations. Inoculations are also given against tetanus and diphtheria.

Antiseptics are chemical substances used to check the growth of microbes and are destructive towards them. They are usually used in or on the human body at the site of infection. They are not as strong as the disinfectants. Common and useful household antiseptics for external use include hydrogen peroxide, mild tincture of iodine, boric acid, and mercurochrome.

Disinfectants are the agents that kill microbes outside the body, generally in the surroundings. Heat and sunlight are natural disinfectants. Chemical disinfectants include phenol, carbolic acid, formalin, various alcohols, chlorinated lime and bleaching powder.

Antibiotics are chemical substances produced by and obtained from certain living organisms such as bacteria, yeasts, and moulds. They are widely used to kill or stop the growth of harmful microbes. Examples of antibiotics are Penicillin, Streptomycin, Aureomycin, Terramycin, Chloramphenicol, and Achromycin.

Penicillin is an antibiotic. It was the first antibiotic and was discovered by Alexander Fleming in 1929. It was first produced in large quantities during World War II. It is obtained from a mould fungus called *Penicillium*. This antibiotic is especially useful in treating diseases such as pneumonia, syphilis, gonorrhea, and throat infections.

Sulphonamide drugs are a group of microbe-fighting drugs. All these drugs, in some form or the other, contain the chemical group called sulphonamide radical, which includes the chemical element sulphur. The drugs are bacteriostatic, i.e., they do not actually kill the bacteria but they interfere with their metabolism in such a way that the latter fail to grow or multiply. Examples of sulphonamide drugs are Sulphadiazine, Sulphathiazole, and Sulphacetamide.

HEALTH ORGANISATIONS

Changing social and economic values of life; the rapidly increasing world population which, unfortunately, outstrips the rate of food production in spite of technical advances in agriculture; the increasing undernutrition and malnutrition; the increasing environmental pollution; the increasing strains and stresses of industrialisation; the increasing amount of diseases; the increasing resistance of the disease-producing organisms, and so on are problems facing mankind today both at the national and international levels. The increased suffering of mankind, or at least the anticipated suffering of mankind in the years to come, has stirred the conscience of many people who have become determined to do something to help. Both at the national and international levels, help is given to the underdeveloped and developing nations by bodies and voluntary organisations supported by various governments.

The following organisations are concerned with public health at the international level.

International Red Cross. This is a voluntary organisation which provides medical and social care during emergencies such as wars, famines, floods, and earthquakes. It also looks after the welfare of refugees. Many countries also have National Red Cross Societies. In addition to the above functions, these societies teach first aid and related skills. They also provide first aid and social services on public occasions.

United Nations International Children's Emergency Fund (UNICEF). This is a United Nations foundation which is concerned with the welfare of children throughout the world. It cooperates with the World Health Organisation regarding matters of child health and often provides medicines or vaccines for mass campaigns.

World Health Organisation (WHO) is a specialised agency of the United Nations Organisation, with headquarters at Geneva in Switzerland. It was founded in 1948. Its responsibilities include the following: It acts as the directing and coordinating authority on international health work and aims at attainment of the highest possible level of health by all people. It organises international campaigns to control or eliminate diseases such as smallpox, measles, and malaria. Besides this, it plays an important role in the eradication of epidemic and endemic diseases. It maintains up-to-date statistical health records for most countries, and acts as 'headquarters' through which health agencies all over the world can contact each other. It also encourages and conducts scientific research, disseminates medical information and standardises diagnostic procedures through seminars, publications, and other media. In addition to regulating international quarantine work, this international organisation controls the issue of International Certificates of Vaccination against certain diseases such as smallpox, yellow fever, and cholera to travellers, who require them before being allowed to enter certain countries.

POLLUTION

The thin shell at the surface of the earth within which all living organisms are found is called the **biosphere**. It is this part of the earth and its atmosphere in which living organisms can exist. It consists of the environment which provides living organisms with all the basic materials and conditions such as carbon dioxide, water, oxygen, light, suitable temperature, and so on.

The environment of an organism consists of the conditions in which it lives and of all the external and internal factors which act on the organism and affect it in some way or the other. Basically, living organisms possess the abilities and adaptations for surviving the physical conditions of their environment: e.g., desert organisms are capable of coping with intense heat and drought; sea organisms can thrive well in salt water; tundra and coniferous forests contain organisms which can withstand long periods of extreme cold, low temperature, etc.

The study of the relationships that exist between living organisms and their environment is called **ecology**. Man is a part of the environment in which he lives and his survival depends on the maintenance and preservation of a stable environment. Man has always been ruthlessly engaged, consciously or unconsciously, in the process of changing his environment by physical and chemical means, to suit his requirements. To some extent, this is inevitable because this is the consequence of the change from a predominantly agricultural society to an industry-based society (and economy) and also of a rise in the population level.

Until recently the effects of this change had not been felt by man to a great extent, but today he is fully aware of the problems he has created and this has led him to re-examine his ruthless attitude towards his environment. He has realised the ill effects of large-scale deforestation; overgrazing of grass lands; indiscriminate use of pesticides and weed killers; discharge of industrial byproducts containing oxides of carbon, sulphur and nitrogen, hydrocarbons, lead, mercury, chlorine, etc.; crude and unscientific disposal of sewage; increasing production of radioactive wastes, etc. All these agents and substances are pollutants and these have polluted the environment. These pollutants are slow poisons not only for man's health and well being but also for other living organisms.

Pollution can occur in the atmosphere or in the soil or in the sea or fresh water, depending on where the pollutants are released.

Air pollution is caused mainly by the release of gases and fine particles from factories, internal combustion engines, generating systems, industrial and domestic fires, and so on. The main pollutants are soot, smoke, tarry residues, ash, sulphur dioxide, carbon monoxide, carbon dioxide, nitric acid, sulphuric acid, hydrogen fluoride, hydrogen sulphide, ethylene, oxides of nitrogen, and lead compounds.

The aforementioned pollutants may enter the tissues of animals and plants directly, through the stomata or lungs, or at any point on the surface. Sometimes, they may be deposited in the soil or in the water, and then absorbed by plants in solution and eventually pass into the bodies of animals when they eat these plants.

The ill effects of some of these pollutants are as follows:

(1) Carbon dioxide may not be so harmful in itself but some scientists predict that a continuous increase in the proportion of this gas in the atmosphere will eventually lead to the formation of a 'blanket' around the earth and cause temperatures to rise. This will not only have serious effects on farming but will also lead to the melting of polar ice caps, rise in ocean levels and consequent flooding of large areas of coastal land.

(2) Sulphur dioxide is poisonous to plants and reduces crop yields. It also aggravates lung diseases.

(3) Smoke is mainly a suspension of carbon particles in air. It also includes oxides of carbon, sulphur and nitrogen, lead and various hydrocarbons. When combined with water vapour, smoke gives rise to smog (a mixture of smoke and fog). Smoke reduces the amount of sunlight reaching the earth, which, in turn, affects photosynthesis. Smoke and smog cause intense eye irritation, headaches, general sickness, and breathing difficulties.

(4) Oxides of nitrogen form compounds which are poisonous to plants and possibly to animals too, and cause eye irritation.

(5) Lead compounds are present chiefly in the fumes released from internal combustion engines since lead compounds are added to fuels as anti-knocking agents. Lead accumulates in bones and slowly poisons the brain, causing paralysis and mental disorders.

Water pollution poses urgent problems because of man's continuously increasing needs for fresh water. Pollution of rivers, streams, ponds, lakes, seas, and other bodies of water is mainly due to the discharge of untreated sewage and industrial wastes run off from chemical fertiliser and insecticide factories when these are used in large amounts. Oil tankers and oil rigs also cause water pollution due to oil spills.

The untreated sewage is likely to contain disease-causing microbes which can contaminate drinking water and fishes. Sewage can also lead to **eutrophication** (deficiency of oxygen), when lakes or ponds may become unfit for the survival of fishes and other animals.

The industrial wastes from factories contain cyanides and toxic compounds of mercury, copper and lead, all of which are harmful to the animals living in water and also for those who feed on these animals. Some wastes contain sulphides and sulphites, which are reducing agents and lower the oxygen concentration in the water.

The excess of fertilisers and insecticides which may be drained to neighbouring fresh water can kill the living organisms in the water and can also cause eutrophication.

Oil escapes from the oil tankers when these are being loaded and unloaded, and it may also be released in large quantities when an oil tanker is wrecked, or an off-shore oil rig explodes. Oil spreads as a thin widely dispersed film on the surface of water and reduces its uptake of oxygen. It also causes the death of sea birds, either by poisoning them or by making their feathers stick together so that they are rendered incapable of flying. Oil can also kill fishes and thus affect the people who fish for a living.

Soil pollution is caused by the excessive use of pesticides and weed killers, which not only kill the harmful crop pests but also have serious side-effects on soil organisms. Whereas the pesticides kill some specific pests, they contaminate the others. When these contaminated pests are eaten by their natural enemies, the pesticides get into the food chain of animals. The pesticide may either kill these animals outright or may affect their reproduction.

When the pesticides happen to kill the microorganisms which play an important role in maintaining the nitrogen cycle in nature, the fertility of the soil is badly affected. Besides, the pesticides and weed killers which are sprayed in excess are washed down by rain into the soil. This too contaminates the soil organisms.

Radioactive pollution involves (1) radiations from nuclear reactors, X-rays and other equipment, (2) radioactive waste, and (3) fallout from thermonuclear explosions. Radioactive substances have an extremely slow rate of decay and can therefore persist as serious health hazards in future years. Besides their immediate effects such as causing leukaemia and bone tumours, radiations cause changes in gene cells which form the sex cells. This is likely to lead to genetic abnormalities in future generations.

Noise pollution poses a major problem for people living in large cities. Excessive noise can damage the ears and a continuous exposure to noise may lead to heart diseases since it makes the muscles tense.

CONTROL MEASURES

(1) Fitting the exhausts of internal combustion engines with filters.
(2) Proper treatment of sewage and industrial wastes to render them harmless before disposal.
(3) Prevention of spillage of oil during loading and unloading of oil tankers.
(4) Ban on nuclear tests.
(5) Use of silencers on the vehicles and checks on the flight of aeroplanes over densely populated areas.

EXERCISES

1. (a) Name six types of microbes which cause human diseases.
   (b) Name five diseases caused by each of the following: (i) pathogenic bacteria; (ii) viruses; and (iii) protozoa.
2. Briefly describe how diseases are spread by air, water, food, and insects. Give examples of such diseases and suggest means of control in each case.
3. State the causes and remedies of five diseases not caused by organisms.
4. Why is it more important to take preventive measures than remedial measures against disease?
5. Differentiate the following from each other: (a) an endemic disease; (b) an epidemic disease; and (c) a pandemic disease.
6. Define the following terms: (a) antibodies; (b) phagocytes; (c) toxins; (d) antigens; and (e) immunity.
7. How do antibodies defend the human body against dangerous microbes? Explain with the aid of three examples.
8. (a) Distinguish clearly between natural immunity and acquired immunity, with the help of examples.
   (b) What is acquired artificial immunity? Name two types of artificial immunity.
9. What are vaccines and how do they protect the body? Name three human diseases against which vaccination is effective.
10. What are serums and how do they protect the body? Name three human diseases against which inoculation is effective.
11. Name three bacteria which can be called parasites.
12. What are the preventive measures against infection by *Plasmodium* and *Taenia*? Name some of the drugs used to cure infections due to these organisms.
13. What advice on personal hygiene would you give to a community where cases of typhoid, cholera, and dysentery have been reported?
14. Why is it unsafe to eat at common market places where the articles of food are not kept covered?
15. What tips on personal hygiene would you give on the care of the mouth, teeth and nose?
16. State different methods by which houseflies, mosquitoes, rats, cockroaches, and pigs spread diseases.
17. How does a serum differ from a vaccine?
18. What is a bacteriostatic agent? Name any two such agents. How do they differ from antibiotics?
19. Distinguish between antiseptics and disinfectants. Give two examples of each.
20. State the chemical compositions of serum and plasma. How is serum obtained?
21. State the general characteristics of viruses. What are the common modes of virus transmission in the environment? What are bacteriophages?
22. State the important functions of the World Health Organisation as the keeper of the health of all people in all countries.
23. What is pollution? Name two pollutants each of air and water.
24. State some of the ways in which man has himself polluted his environment.
25. What effects do lead, mercury, carbon dioxide, sulphur dioxide and radioactive fallout have on human life?
26. In what ways is the soil polluted? How does this pollution affect agricultural production?
27. Suggest some methods to check pollution in the locality in which you live.
28. Explain the following terms: biosphere, ecology, environment, deforestation, and sewage.

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